Contents

PROPOSED SYLLABUS

B.Sc. (Part II) Chemistry
ORGANIC CHEMISTRY-II
(SC-119)

UNIT–I : ALCOHOLS AND PHENOLS

Alchols : Classification and nomenclature.

Monohydric alcohols : Nomenclature, methods of formation by reduction of aldehydes, ketones, carboxylic acids and esters, reactions of alcohols.

Dihydric alcohols : Nomenclature, methods of formation and chemical reactions.

Trihydric alcohols : Nomenclature and methods of formation, chemical reactions of glycerol.

Nomenclature, preparation of phenols, physical properties and acidic character, comparative acidic strength of alcohols and phenols, Reactions of phenols. Mechanism of Fries rearrangement, Claisen rearrangement, Reimer-Tiemann reaction. Methods of preparation and properties of picric acid.

UNIT–II : CARBOXYLIC ACIDS

Methods of formation and chemical reactions of tartaric acid, citric acid, malic acid, malonic acid, benzoic acid, salicylic acid, anthranilic acid.

UNIT–III : ORGANOMETALLIC COMPOUNDS AND AROMATIC SULPHONIC COMPOUNDS

Grignard reagents : Formation and chemical reactions, organolithium and organosulphur compounds, thiols and sulphanol.

Sulphonation, preparation and properties of benzene sulphonic acid, saccharin, chloramines-T.

UNIT-IV : POLYNUCLEAR HYDROCARBONS AND HETEROCYCLIC COMPOUNDS

Polynuclear hydrocarbons : Naphthalene and its constitution, preparation, properties and uses, Anthracene : preparation properties of uses.

Heterocyclic compounds : Introduction, aromatic characteristics of pyrrol, furan, thiophene and pyridine. Methods of synthesis and chemical reactions with particular emphasis on the mechanism of electrophilic substitution preparation, properties and uses of indole, quinoline, and isoquinoline. Fischer-indole synthesis.

UNIT-V : REACTIVE METHYLENE COMPOUNDS

Acidity of □-hydrogen. Sythetic applications of diethyl malonate and ethyl acetacetate. Synthesis of diethyl malonate and ethyl acetacetate. Claisen condensation, keto-enol tautomerism of ethyl acetoacetate.

UNIT-VI : SULPHA DRUGS

Sulpha drugs, mechanism of their action, synthesis and uses of sulphacetamide, sulphaguanidine, sulphapyridine, sulphadiazine, sulphathiazole, sulphamethazine.

UNIT

1

ALCOHOLS AND PHENOLS

LEARNING OBJECTIVES

- **Classification and Nomenclature of Alcohols**
- **Primary, Secondary and Tertiary Alcohols and Their Interconversions**
- **Method of Preparation of Alcohols**
- **Ethyls Alcohol or Ethanol**
- **Distinction Between Primary, Secondary and Tertiary Alcohols**
- **Lucas Reagent or Lucas Test**
- **Dehydration of Ethanol**
- **Explanation of Facts Regarding Alcohols**
- **Glycols**
- **Glycerol**
- **Phenols**
- **Interconversions of Phenol**
- **Explanation of Facts Regarding Phenols**
- **Fries rearrangement**
- **Claisen rearrangement**
- **Riemer-Tieman Reaction**
- **Pieric Acid**
    - **Summary**
    - **Student Activity**
    - **Test Yourself**

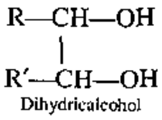
• 1.1. CLASSIFICATION AND NOMENCLATURE OF ALCOHOLS

[I] Classification of Alcohols

Those alcohols which contain one hydroxyl group are called monohydric alcohols. Alcohols with two, three or more hydroxyl groups are called dihydric, trihydric and polyhydric alcohols, respectively. For example,

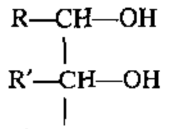
$R—OH$

Monohydric alcohol



$$\begin{array}{c} R—CH—OH \\ | \\ R'—CH—OH \end{array}$$

Dihydricalcohol



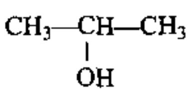
$$\begin{array}{c} R—CH—OH \\ | \\ R'—CH—OH \\ | \\ R''—CH—OH \end{array}$$

Trihydric alcohol

[II] Nomenclature of Alcohols

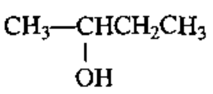
(i) Common naming system. This system is useful for naming simple alcohol. In this system, alcohols (R—OH) are called alkyl alcohols. The alkyl group attached to the —OH group is named and the word alcohol is added to it, *e.g.*,

$CH_3—OH$	$CH_3CH_2—OH$	$CH_3CH_2CH_2—OH$
Methyl alcohol	Ethyl alcohol	*n*–Propyl alcohol



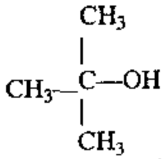
$CH_3-\underset{\underset{OH}{|}}{CH}-CH_3$

Isopropyl alcohol



$CH_3-\underset{\underset{OH}{|}}{C}HCH_2CH_3$

Sec. butyl alcohol



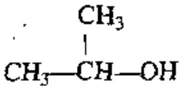
$CH_3-\overset{\overset{CH_3}{|}}{\underset{\underset{CH_3}{|}}{C}}-OH$

Test butyl alcohol

(ii) Carbinol naming system. Alcohols are considered as derivatives of methyl alcohol which is known as *carbinol*. The alkyl groups attached to the carbon atom bearing the —OH group are named in alphabetical order before the suffix carbinol and the whole name is written as on word, *e.g.*,

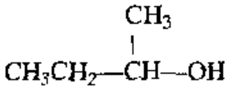
CH_3OH
Carbinol

$CH_3CH_2—OH$
Methylcarbinol



$CH_3-\overset{\overset{CH_3}{|}}{CH}-OH$

Dimethylcarbinol



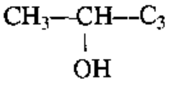
$CH_3CH_2-\overset{\overset{CH_3}{|}}{CH}-OH$

Ethylmethylcarbinol

(iii) IUPAC naming system. In this system. the suffix –'*ol*' is added in place of suffix '*e*' in the name of hydrocarbon. In general, alcohols are named as alkanols, alkenols, alkynols etc. *e.g.*,

$CH_3—OH$
Methanol

$CH_3CH_2—OH$
Ethanol



$CH_3-\underset{\underset{OH}{|}}{CH}-C_3$

2–Ppropanol

$CH_2=CH—CH_2OH$
2-Propen-1-ol

$C_6H_5CH_2CH_2OH$
2-Phenylethanol

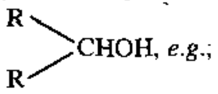
• 1.2. PRIMARY, SECONDARY AND TERTIARY ALCOHOLS AND THEIR INTERCONVERSIONS

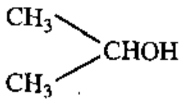
[I] Primary, Secondary and Tertiary Alcohols

(i) Primary alcohol : Primary alcohols contain $—CH_2OH$ group. They have the general formula, $R—CH_2OH$ (where R is H atom or alkyl group), *e.g.*,

$R—CH_2OH$	$H—CH_2OH$	$CH_3—CH_2OH$
General formula	Methyl alcohol	*Ethyl alcohol*

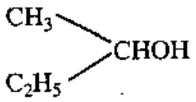
They are also known as 1° alcohols, because —OH group is attached to primary carbon atom.

(ii) Secondary alcohol : Secondary alcohols contain > CHOH group. They have the general formula  $\begin{matrix}R\\R\end{matrix}\!>CHOH$, *e.g.*,



$\begin{matrix}CH_3\\CH_3\end{matrix}\!>CHOH$

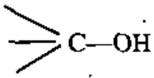
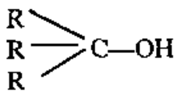
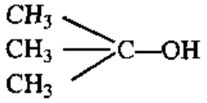
Isopropyl alcohol



$\begin{matrix}CH_3\\C_2H_5\end{matrix}\!>CHOH$

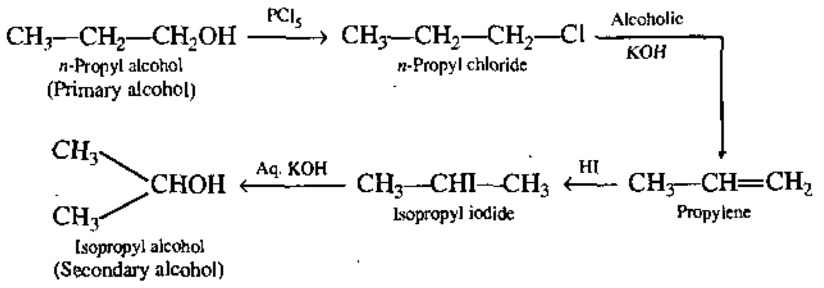
Secondary butyl alcohol

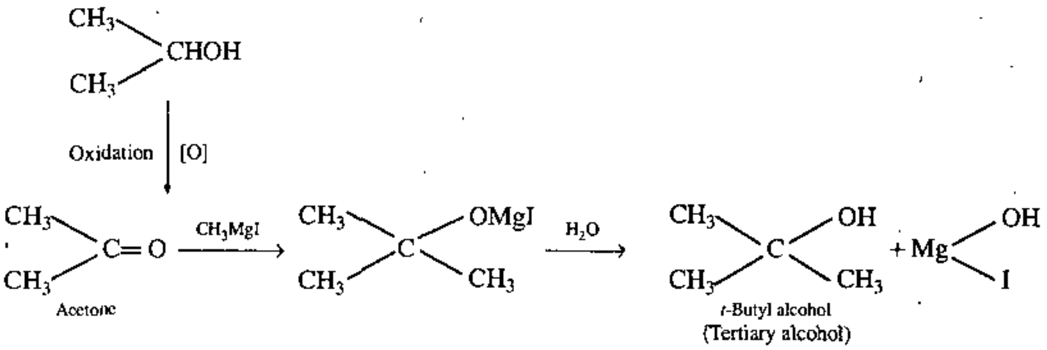
They are also known as 2° alcohols, because —OH group is attached to secondary carbon atom.

(iii) Tertiary alcohol : Tertiary alcohols contain  $-\!\!\!>C—OH$ group. They have the general formula  $\begin{matrix}R\\R\\R\end{matrix}\!>C—OH$, *e.g.*,  $\begin{matrix}CH_3\\CH_3\\CH_3\end{matrix}\!>C—OH$

t-Butyl alcohol

[II] Conversion of Primary Alcohol into Secondary Alcohol & then to Tertiary Alcohol

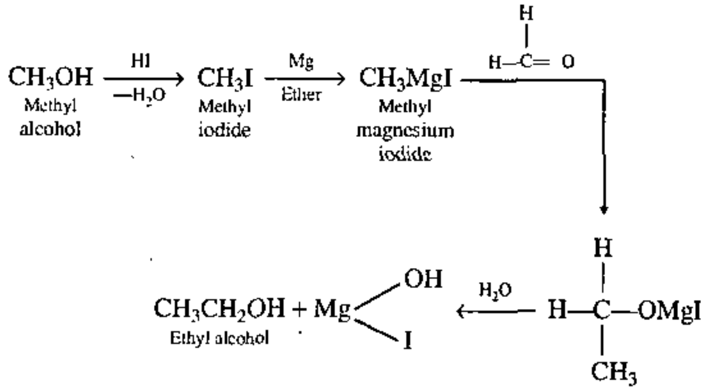




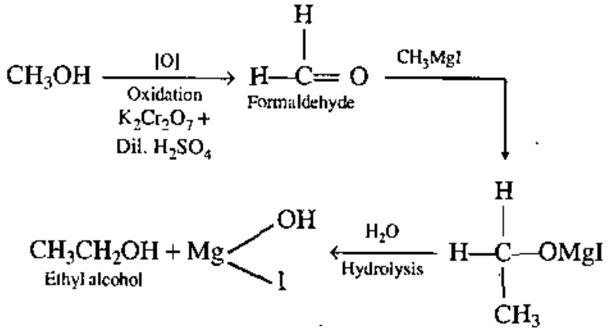
[III] Conversion of Methyl Alcohol into Ethyl Alcohol

Methyl alcohol can be converted into ethyl alcohol by any of the following methods.

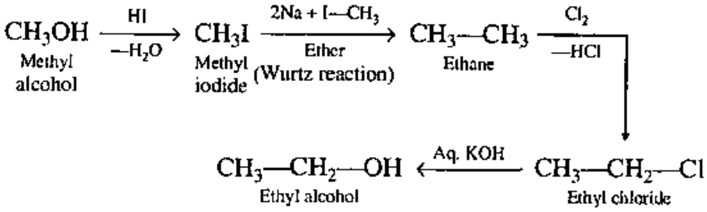
(a)



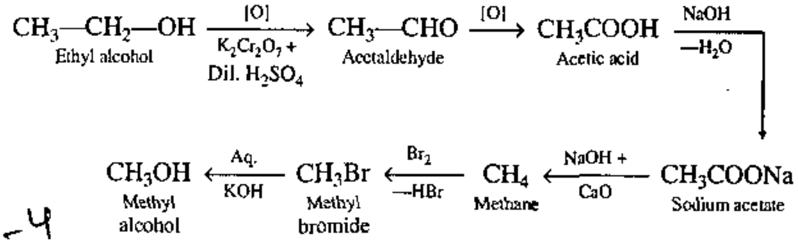
(b)



(c)



[IV] Conversion of Ethyl Alcohol into Methyl Alcohol



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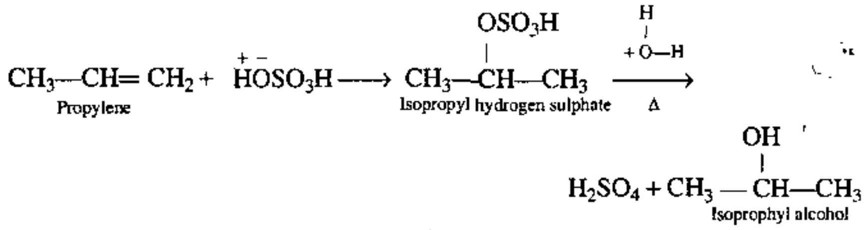
1.3. METHODS OF PREPARATION OF ALCOHOLS

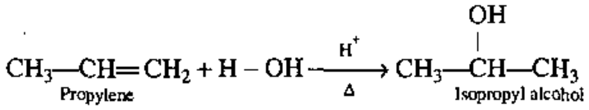
Alcohols are prepared by the following methods :

(i) Hydration of alkenes : Alkenes react with sulphuric acid to from alkyl hydrogen sulphates, which on hydrolysis give alcohols. For example,



$$\underset{\text{Propylene}}{CH_3{-}CH{=}CH_2} + \overset{+\ -}{H\,OSO_3H} \longrightarrow \underset{\text{Isopropyl hydrogen sulphate}}{CH_3{-}\overset{\overset{OSO_3H}{|}}{C}H{-}CH_3} \xrightarrow[\Delta]{+\overset{H}{\overset{|}{O}}-H} H_2SO_4 + \underset{\text{Isoprophyl alcohol}}{CH_3 - \overset{\overset{OH}{|}}{C}H{-}CH_3}$$

The overall result of the above reaction appeas to be Markownikoff's addition of H_2O (hydration) to a double bond.



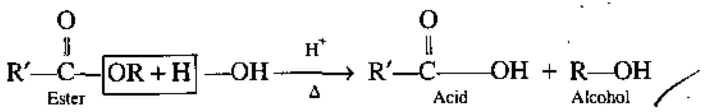
$$\underset{\text{Propylene}}{CH_3{-}CH{=}CH_2} + H - OH \xrightarrow[\Delta]{H^+} \underset{\text{Isopropyl alcohol}}{CH_3{-}\overset{\overset{OH}{|}}{C}H{-}CH_3}$$

(2) Hydrolysis of alkyl halides : Alkyl halides react with aqueous sodium hydroxide to form alcohols.

$$R{-}X + NaOH \xrightarrow[\Delta]{H_2O} \underset{\text{Alcohol}}{R{-}OH} + NaX$$

$$CH_3CH_2{-}Br + NaOH \xrightarrow[\Delta]{H_2O} \underset{\text{Ethayl alcohol}}{CH_2CH_2{-}OH} + NaBr$$

(3) Hydrolysis of esters : Alcohols may be prepared by acid of basic catayseds hydrolysis of esters.



$$\underset{\text{Ester}}{R'{-}\overset{\overset{O}{\|}}{C}{-}}\boxed{OR + H}{-}OH \xrightarrow[\Delta]{H^+} \underset{\text{Acid}}{R'{-}\overset{\overset{O}{\|}}{C}{-}OH} + \underset{\text{Alcohol}}{R{-}OH}$$

(4) Hydroboration-oxidation of alkenes : Alkenes react with diborane, B_2H_6 to form trialkylboranes. Diborane adds as borane, BH_3. The positive part of BH_3 is the boron, the negative part is hydrogen. For example,

$$3\ \underset{\text{Propylene}}{CH_3{-}CH{=}CH_2} + BH_3 \longrightarrow \underset{\text{Tripropyl borane}}{(CH_3CH_2CH_2)_3\,B}$$

Trialkylboranes are used to prepare primary alcohols by reaction with alkaline aqueous solution of H_2O_2.

$$(CH_3CH_2CH_2)_3\,B + H_2O_2 \xrightarrow{^-OH} \underset{\substack{\text{n-Propyl alcohol}\\ \text{(1-propanol)}}}{3CH_3CH_2CH_2OH} + H_2BO_3$$

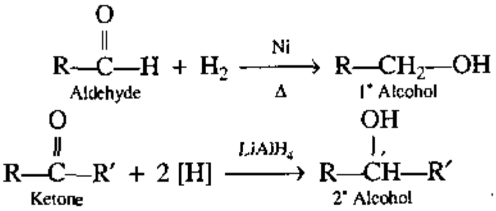
The overall result of the above reaction appears to be anti-Markownikoff addition of H_2O to a double bond.

$$\underset{\text{Propylene}}{CH_3{-}CH = CH_2} \xrightarrow[\text{(ii) } H_2O/OH^-]{\text{(i) } B_2H_6} \underset{\text{n-Propyl alcohol}}{CH_3CH_2CH_2OH}$$

(5) Fermentation of carbohydrates : Some alcohols can be prepared by fermentation of starches and sugars under the effect of suitable enzymes. For example,

$$\underset{\text{Glucose}}{C_6H_{12}O_6} + \text{Yeast} \xrightarrow{\text{Fermentation}} \underset{\text{Ethyl alcohol}}{2CH_3CH_2OH} + 2CO_2\uparrow$$

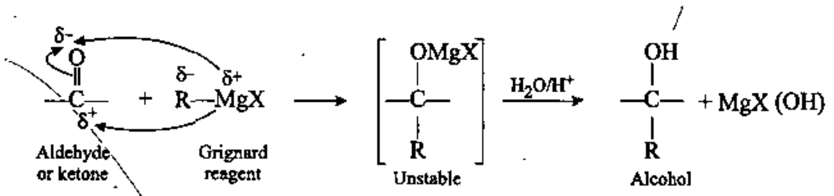
(6) Reduction of aldehydes and ketones : *Aldehydes and ketones can be reduced with* H_2/Ni or lithium aluminium hydride ($LiAlH_4$) to form the corresponding alcohols. Aldehydes give primary alcohols. Ketones give secondary alcohols.



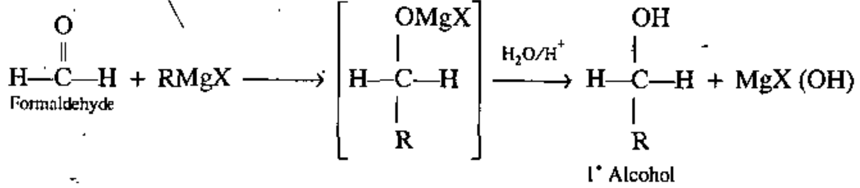
$$\underset{\text{Aldehyde}}{R{-}\overset{\overset{O}{\|}}{C}{-}H} + H_2 \xrightarrow[\Delta]{Ni} \underset{\text{1° Alcohol}}{R{-}CH_2{-}OH}$$

$$\underset{\text{Ketone}}{R{-}\overset{\overset{O}{\|}}{C}{-}R'} + 2\,[H] \xrightarrow{LiAlH_4} \underset{\text{2° Alcohol}}{R{-}\overset{\overset{OH}{|}}{C}H{-}R'}$$

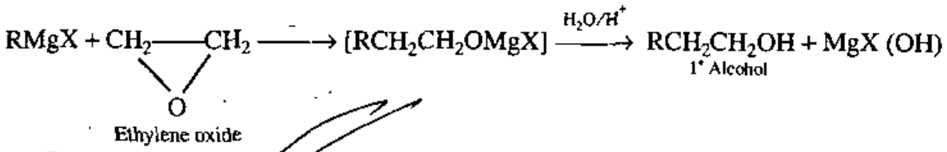
(7) Addition of Grignard reagent to aldehydes and ketones : Grignard reagents react with aldehydes or ketones to form the addition compound which on hydrolysis with dilute acid gives the corresponding alcohols.



(i) Primary alcohols are obtained by treating a Grignard reagent with HCHO or ethylene oxide.

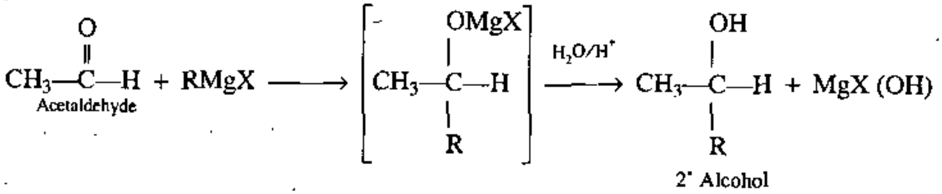


$$\underset{\text{Formaldehyde}}{H-\overset{\overset{O}{\|}}{C}-H} + RMgX \longrightarrow \left[H-\underset{R}{\overset{OMgX}{C}}-H\right] \xrightarrow{H_2O/H^+} \underset{1^\circ\text{ Alcohol}}{H-\underset{R}{\overset{OH}{C}}-H} + MgX\,(OH)$$



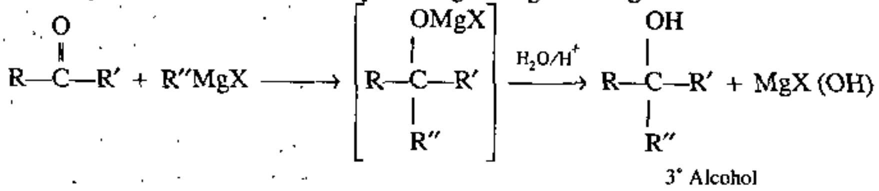
$$RMgX + \underset{\text{Ethylene oxide}}{\underset{\diagdown O \diagup}{CH_2-CH_2}} \longrightarrow [RCH_2CH_2OMgX] \xrightarrow{H_2O/H^+} \underset{1^\circ\text{ Alcohol}}{RCH_2CH_2OH} + MgX\,(OH)$$

(ii) Secondary alcohols are obtained by treating a Grignard reagent with aldehydes other than formaldehyde.



$$\underset{\text{Acetaldehyde}}{CH_3-\overset{\overset{O}{\|}}{C}-H} + RMgX \longrightarrow \left[CH_3-\underset{R}{\overset{OMgX}{C}}-H\right] \xrightarrow{H_2O/H^+} \underset{2^\circ\text{ Alcohol}}{CH_3-\underset{R}{\overset{OH}{C}}-H} + MgX\,(OH)$$

(iii) Tertiary alcohols are obtained by treating a Grignard reagent with ketones.



$$R-\overset{\overset{O}{\|}}{C}-R' + R''MgX \longrightarrow \left[R-\underset{R''}{\overset{OMgX}{C}}-R'\right] \xrightarrow{H_2O/H^+} \underset{3^\circ\text{ Alcohol}}{R-\underset{R''}{\overset{OH}{C}}-R'} + MgX\,(OH)$$

1.4. ETHYL ALCOHOL OR ETHANOL

[I] Preparation of Ethanol

(i) From ethyl halide :

$$\underset{\text{Ethyl iodide}}{C_2H_5I} + \underset{\text{Aq.}}{KOH} \longrightarrow C_2H_5OH + KI$$

$$\underset{\text{Ethyl bromide}}{C_2H_5Br} + \underset{\text{Moist silver oxide}}{AgOH} \longrightarrow C_2H_5OH + AgBr$$

(ii) From ethyl acetate :

$$CH_3COOC_2H_5 + NaOH \longrightarrow CH_3COONa + C_2H_5OH$$

(iii) By the reduction of aldehyde, ketone, carboxylic acid, acid chloride and ester with $LiAlH_4$:

$$\underset{\text{Acetaldehyde}}{CH_3CHO} + 2H \xrightarrow{LiAlH_4} \underset{\text{Ethyl alcohol}}{CH_3CH_2OH}$$

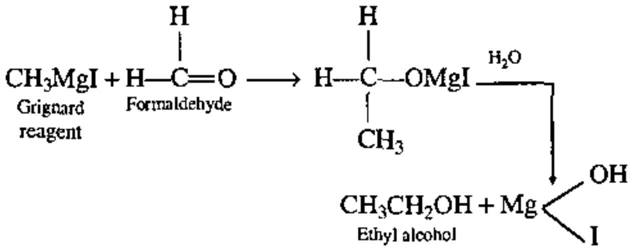
$$\underset{\text{Acetone}}{CH_3COCH_3} + 2H \xrightarrow{LiAlH_4} \underset{\text{Iso propyl alcohol}}{CH_3CHOHCH_3}$$

$$\underset{\text{Acetic acid}}{CH_3COOH} + 4H \xrightarrow{LiAlH_4} CH_3CH_2OH + H_2O$$

$$\underset{\text{Acetyl chloride}}{CH_3COCl} + 4H \xrightarrow{LiAlH_4} CH_3CH_2OH + HCl$$

$$\underset{\text{Ethyl acetate}}{CH_3COOC_2H_5} + 4H \xrightarrow{LiAlH_4} \underset{\text{Ethyl alcohol}}{CH_3CH_2OH + C_2H_5OH}$$

(iv) From Grignard reagent :



$$\underset{\text{Grignard reagent}}{CH_3MgI} + \underset{\text{Formaldehyde}}{H-\overset{H}{\overset{|}{C}}=O} \longrightarrow H-\overset{H}{\overset{|}{\underset{CH_3}{\underset{|}{C}}}}-OMgI \xrightarrow{H_2O} \underset{\text{Ethyl alcohol}}{CH_3CH_2OH} + Mg\begin{matrix} OH \\ I \end{matrix}$$

(v) From ether :

$$\underset{\text{Diethyl ether}}{C_2H_5-O-C_2H_5} + H_2O \xrightarrow{\text{Dil. } H_2SO_4} 2C_2H_5OH$$

(vi) From ethyl amine :

$$\underset{\text{Ethyl amine}}{C_2H_5NH_2} + HNO_2 \longrightarrow \underset{\text{Ethyl alcohol}}{C_2H_5OH} + H_2O + N_2$$

[II] Manufacture of Ethanol

(A) From molasses :

Molasses contains about 50% cane sugar, glucose and fructose. Molasses is converted to ethyl alcohol by means of yeast. Ethyl alcohol is produced in the following steps.

(i) Preparation of wash : Molasses is diluted with water so as to get a 8–10% solution of sugar. A small amount of dilute sulphuric acid is added to check the growth of undesirable bacteria. To this solution, a small quantity of ammonium sulphate and ammonium phosphate is added which act as a food for ferment (yeast) cells. Yeast is now added to it after maintaining the temperature between 25°–30°C. Invertase and zymase enzyme of yeast react with molasses sugar and so ethyl alcohol is produced.

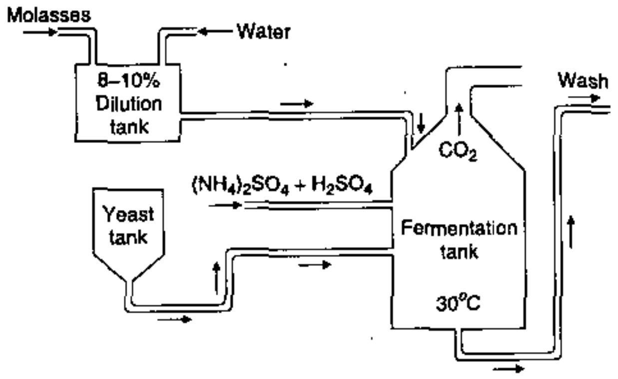


Fig. 1. Manufacture of ethanol from molasses.

$$\underset{\text{Sucrose}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow[\text{yeast}]{\text{Invertase}} \underbrace{\underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Fructose}}{C_6H_{12}O_6}}_{\text{Invert sugar}}$$

$$\underset{\text{Invert sugar}}{C_6H_{12}O_6} \xrightarrow[\text{(Yeast)}]{\text{Zymase}} 2CO_2 + 2C_2H_5OH$$

This process is completed in 2–3 days when evolution of carbon dioxide ceases and yeast is filtered off. The filterate is known as **wash** which contains about 10% ethanol.

(ii) Distillation of wash : The wash is subjected to fractional distillation using special fractionating columns called coffey stills. Each coffey still consists of two fractionating columns called as ***analyser*** and ***rectifier*** which are provided with perforated horizontal plates having valves opening upwards.

The wash is pumped into coiled pipes where it is preheated and enters analyser from the top end. A current of steam is passed from bottom end which comes in contact with down coming wash. It vaporises the alcohol present in wash and takes away the alcohol vapours with itself and leaves from the top end. It then enters in rectifier near the base. Here condensation takes place, first alcohol condenses due to low b.p. (78·3°C) than water condenses. The uncondensed alcohol vapours leave the rectifier at its top end and are condensed with the help of a condenser. Alcohol thus obtained is 90% pure.

(iii) Rectification : The 90% ethanol, as obtained above is subjected to fractional distillation when the following fractions are obained.

(a) First fraction : This fraction contains low boiling liquids like acetaldehyde.

(b) Second fraction : This fraction contains 93–95% ethanol and is called as rectified spirit.

(c) Last fraction : This fraction contains water and fusel oil. Fusel oil is a mixture of *n*-propyl, *n*-butyl, *n*-amyl, isoamyl and optically active amyl alcohols.

(B) From starch

Following steps are involved in the manufacture of ethanol from starch : (a) Saccharification (b) Alcoholic fermentation.

(1) Saccharification : Starch is first converted to maltose. This conversion is known as saccharification and completed in following steps.

(a) Malting : Moist barley seeds are allowed to germinate in dark room at 15°C, temperature is raised to 60° after complete germination. Germinated seeds are known as **malt** and contain diastase enzyme. The seeds are now crushed with water and filtered. The filterate is called *malt extract.*

(b) Mashing : Starchy materials like potato, rice or maize are crushed and heated with super heated steam. Starch granules come out of the cell wall and form a paste with water. This is known as *mash.*

(c) Hydrolysis : Mash is heated to 50–60°C and malt extract added to it. Diastase enzyme (malt) hydrolyses starch (mash) into maltose sugar. This process is completed in nearly half an hour.

$$\underset{\text{Starch (mash)}}{2(C_6H_{10}O_5)_n} + nH_2O \xrightarrow[\text{(Malt extract)}]{\text{50–60°, Diastase}} \underset{\text{Maltose}}{nC_{12}H_{22}O_{11}}$$

(2) Alcoholic fermentation : The above solution of maltose is cooled to 30°C and yeast is added to it. Alcoholic fermentation sets in and enzyme present in yeast converts maltose inethyl alcohol.

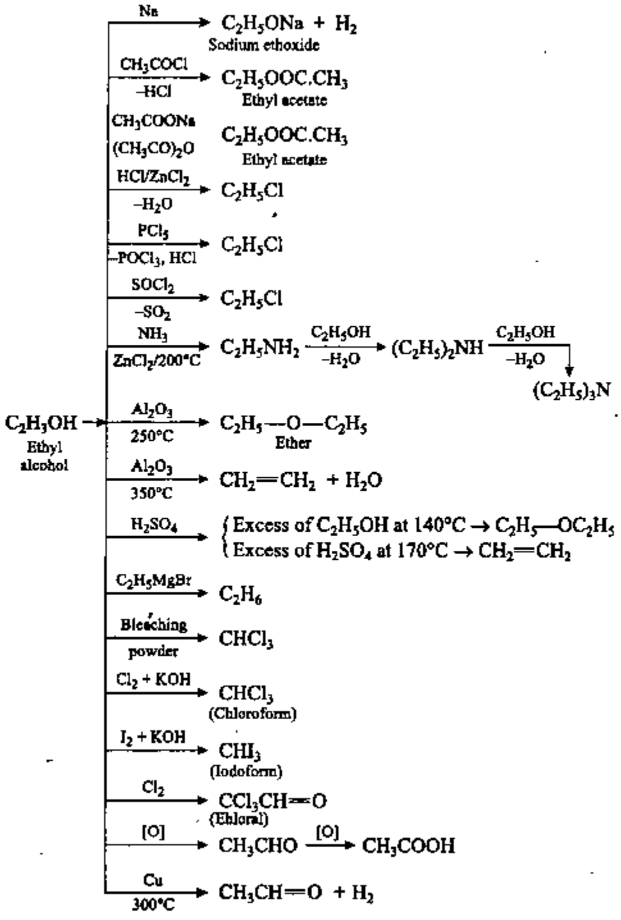
$$\underset{\text{Maltose}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow[\text{(Yeast)}]{\text{Maltase, 30°C}} \underset{\text{Glucose}}{2C_6H_{12}O_6}$$

$$C_6H_{12}O_6 \xrightarrow[\text{(Yeast)}]{\text{Zymase}} 2CO_2 + 2C_2H_5OH$$

The concentration of alcohol in this solution called wash is about 10%. From this rectifed spirit is obtained by the same method as discussed earlier.

[III] Chemical Properties of Ethyl Alcohol

The properties of ethyl alcohol are summarised as follows :



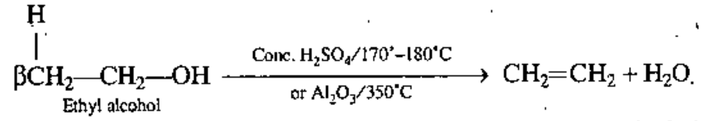
[IV] Uses of Ethanol

Ethyl alcohol is used :

(i) As an alcoholic beverage. (ii) As a solvent for paints, drugs, oils, dyes etc.

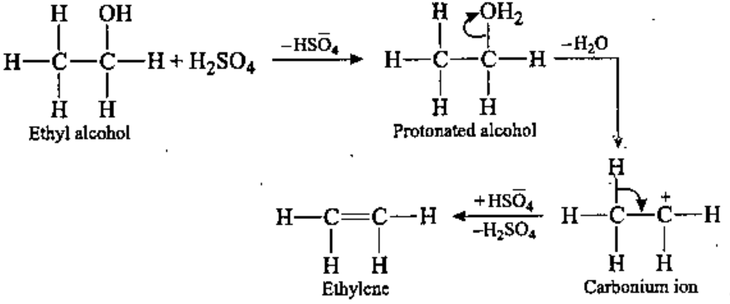
1.5. DEHYDRATION OF ETHANOL

(a) Formation of alkenes : Alcohols, containing at least one β-hydrogen atom, undergo dehydration (elimination of water) when heated to 170°-180°C with concentrated sulphuric acid or when its vapours are passed over alumina heated to 350°C.



$$\underset{\text{Ethyl alcohol}}{\overset{\text{H}}{\beta\text{CH}_2}\text{—CH}_2\text{—OH}} \xrightarrow[\text{or } Al_2O_3/350°C]{\text{Conc. } H_2SO_4/170°-180°C} CH_2{=}CH_2 + H_2O.$$

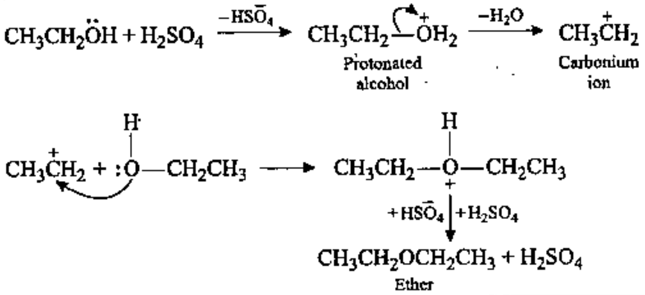
The ease of formation of alkene is in the order of *tertiary alcohol* > *secondary alcohol* > *primary alcohol* depending on the stability of corresponding carbonium ions formed, *i.e., tertiary* > *secondary* > *primary,* during the reaction. The mechanism of the reaction is :



(b) Formation of ethers : If the dehydration of an alcohol with sulphuric acid is carried out in presence of an excess of alcohol at comparatively lower temperatures (130°—140°C) or when its vapours are passed over alumina heated to 250°C, the product is a dialkyl ether.

$$2CH_3CH_2OH \xrightarrow[Al_2O_3,\ 250°C]{\text{Conc. } H_2SO_4,\ 130°-140°C} \underset{\text{Diethyl ether}}{CH_3CH_2.O.CH_2CH_3} + H_2O$$

The mechanism of reaction is as follows :



Ans-5

1.6. DISTINCTION BETWEEN PRIMARY, SECONDARY AND TERTIARY ALCOHOLS

The three types of alcohols can be distinguished by the following tests :

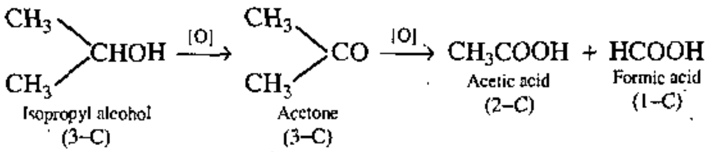
[I] By Oxidation

The primary, secondary and tertiary alcohols may be distinguished through their oxidation products.

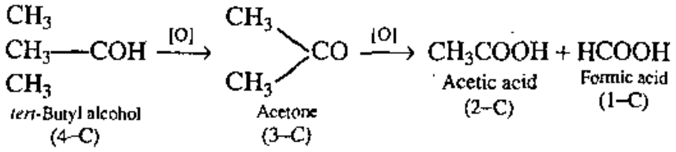
(a) A primary alcohol on oxidation first gives an aldehyde and this on further oxidation, forms a carboxylic acid. Both the aldehyde and the carboxylic acid contain the same number of carbon atoms as the original alcohol, *e.g.,*

$$\underset{\substack{\text{Ethyl alcohol}\\(2\text{–C})}}{CH_3CH_2OH} \xrightarrow{[O]} \underset{\substack{\text{Acetaldehyde}\\(2\text{–C})}}{CH_3CHO} \xrightarrow{[O]} \underset{\substack{\text{Acetic acid}\\(2\text{–C})}}{CH_3COOH}$$

(b) A secondary alcohol on oxidation first gives a ketone with same number of carbon atoms as the original alcohol. Further oxidation of ketone forms a mixture of carboxylic acids, each containing lesser number of carbon atoms than the original alcohol, *e.g.,*



(c) A tertiary alcohol on oxidation first gives a ketone which on further oxidation forms a mixture of carboxylic acids. All the oxidation products, *i.e.*, ketone and acids contain lesser number of carbon atoms individually than the original alcohol.



The oxidising agents usually used are, *dilute nitric acid, acidic or alkaline potassium permanganate and acidic potassium dichromate.*

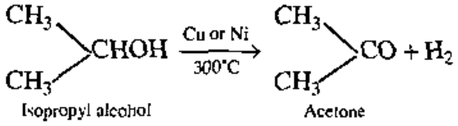
[II] By Passing Alcohol Vapours over Copper or Nickel Heated to 300°C

The three classes of alcohols differ in their behaviour when their vapours are passed over heated copper or nickel.

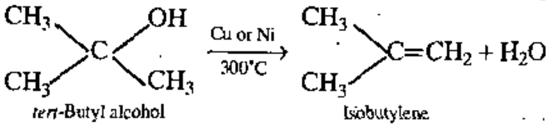
(a) *A primary alcohol* undergoes *dehydrogenation* to form an *aldehyde, e.g.,*

$$\underset{\text{Ethyl alcohol}}{CH_3CH_2OH} \xrightarrow[300^\circ C]{\text{Cu or Ni}} \underset{\text{Acetaldehyde}}{CH_3CHO} + H_2$$

(b) *A secondary alcohol* also undergoes *dehydrogenation* to form a *ketone, e.g.,*



(c) *A tertiary alcohol*, on the other hand, undergoes *dehydration* to produce an *olefin, e.g.,*

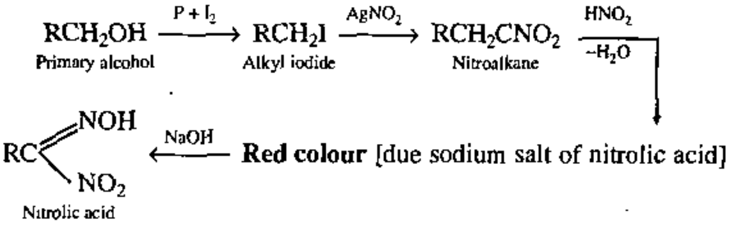


[III] By Victor Meyer's Method

Victor Meyer's method is perhaps the best method of distinction since the final products formed, are coloured. The method includes a set of reactions. First an alcohol is converted into its corresponding iodide by treating with phosphorus and iodine, which is then heated with silver nitrite. The resulting nitroparaffin is treated with nitrous acid and alkali.

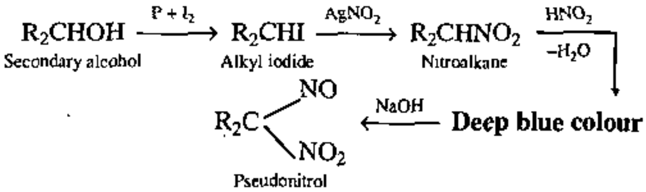
On the basis of the above treatment, a *primary alcohol* gives a *red colour,* a *secondary alcohol* gives *deep blue colour*, while a *tertiary alcohol* gives *colourless solution*. The reactions may be written as :

(i)



Red colour [due sodium salt of nitrolic acid]

(ii)



Deep blue colour

(iii)

$$\underset{\text{Tertiary alcohol}}{R_3COH} \xrightarrow{P + I_2} \underset{\text{Alkyl iodide}}{R_3CI} \xrightarrow{AgNO_2} \underset{\text{Nitroalkane}}{R_3CNO_2} \xrightarrow{HNO_2} \text{No reaction} \xrightarrow{NaOH} \textbf{Colourless.}$$

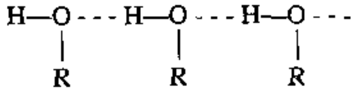
• 1.7. LUCAS REAGENT OR LUCAS TEST

Lucas test is the simplest method for distinction of alcohols. Lucas reagent is a mixture of anhydrous zinc chloride and concentrated hydrochloric acid. When an alcohol is mixed with Lucas reagent, an alkyl chloride is formed. Since alkyl chlorides are insoluble in water, a turbidity in obtained. At room temperature, a *tertiary alcohol* gives the turbidity *immediately, a secondary alcohol* gives the turbidity *within 5 minutes*, while a *primary alcohol* does *not* give *any turbidity at room temperature.*

• 1.8. EXPLANATION OF FACTS REGARDING ALCOHOLS

(i) ***Alcohols have higher boiling points than isomeric ethers. Explain.***

The high boiling point of alcohols is due to their ability to form H-bonds between their molecules. The H-bond formation takes place between oxygen atom of one molecule and hydrogen atom of another molecule as shown below :



$$\begin{array}{lll} H-O\cdots & H-O\cdots & H-O\cdots \\ \quad | & \quad | & \quad | \\ \quad R & \quad R & \quad R \end{array}$$

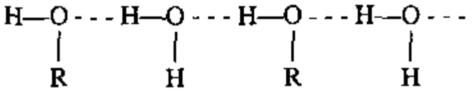
A considerable amount of energy is required for breaking these H-bonds. Hence, boiling points of alcohols are higher than ethers. The H-bonding is not found in ethers, hence their boiling points are low.

(ii) ***Hydrogen bonding occurs in the molecules of H_2O, CH_3OH and C_2H_5OH, then why H_2O having so less molecular weight have so high boiling point?***

Hydrogen bonding occurs in the molecules of H_2O, CH_3OH and C_2H_5OH, but in the case of H_2O both H-atoms can form H-bonds, whereas in the case of alcohols, there is only one H-atom which can form H-bonds. Thus, H-bonding in water is more significant than in alcohols. Hence, a greater amount of energy is required for breaking these H-bond. As a result of this, water has much higher boiling point than alcohols.

(iii) ***Alcohols are soluble in water, whereas ethers are insoluble in water. Why ?***

Alcohols which form the H-bonds in their molecules, can also form H-bonds with water molecules. Hence, a sort of co-association occurs between alcohol and water molecules through H-bonding.

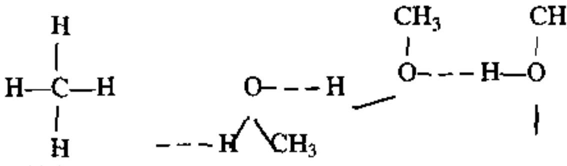


$$\begin{array}{llll} H-O\cdots & H-O\cdots & H-O\cdots & H-O\cdots \\ \quad | & \quad | & \quad | & \quad | \\ \quad R & \quad H & \quad R & \quad H \end{array}$$

This co-association of alcohol and water molecules through H-bonding is responsible for the solubility of alcohols in water. Ethers are insoluble in water because they cannot form H-bonds.

(iv) ***The boiling point of an alcohol is higher than that of corresponding alkane. Why ?***

Alkanes are non-polar compounds with only weak intermolecular attractions. So, they have a low boiling point. Alcohols have strong attraction between molecules owing to their capacity of hydrogen bonding and so they have a comparatively higher boilding points than alkanes.



Methane
(No H-bonding)

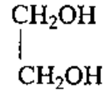
Methyl alcohol H bonding

(v) ***Explain the acidity of alcohols.***

Alcohol have —OH group and because of the presence of lone pair of electrons on the oxygen of the —OH group, alcohols behave as bases. However, they also behave as weak acids. The acidity of alcohols can be explained on the basis of the fact that hydrogen atom is attached to electronegative oxygen atom, which contain a pair of electrons of the O—H bond. So, there is a tendency of the loss of hydrogen as proton. In other words the acidic nature of alcohols is due to the ability of oxygen to accommodate the negative charge after the loss of proton. Therefore, alcohols react with strong electropositive metals (Na, K, etc.) with evolution of hydrogen to produce alkoxides.

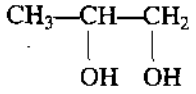
• 1.9. GLYCOLS

Dihydric alcohols are known as glycols. These contain two hydroxyl groups attached to different carbon atoms. For example,



$$\begin{array}{l} CH_2OH \\ | \\ CH_2OH \end{array}$$

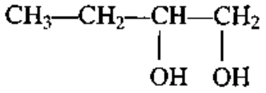
Ethylene glycol
(Ethane 1, 2 diol)



$$CH_3-\underset{OH}{\underset{|}{CH}}-\underset{OH}{\underset{|}{CH_2}}$$

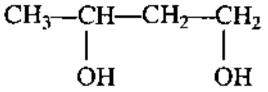
Propylene glycol
(Propane 1, 2 diol)

Glycols are classified as α, β, γ glycols depending upon the relative positions of two hydroxyl groups. 1, 2 glycol is termed as α, 1, 3 glycol is termed as β, 1, 4 glycol is known as γ and so on.



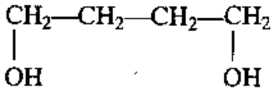
$$CH_3-CH_2-\underset{OH}{\underset{|}{CH}}-\underset{OH}{\underset{|}{CH_2}}$$

Butane 1, 2 diol
(α-Glycol)



$$CH_3-\underset{OH}{\underset{|}{CH}}-CH_2-\underset{OH}{\underset{|}{CH_2}}$$

Butane 1, 3 diol
(β-Glycol)



$$\underset{OH}{\underset{|}{CH_2}}-CH_2-CH_2-\underset{OH}{\underset{|}{CH_2}}$$

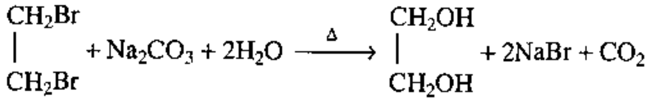
Butane 1, 4 diol

Common glycol is ethylene glycol.

[I] Preparation of Ethylene Glycol

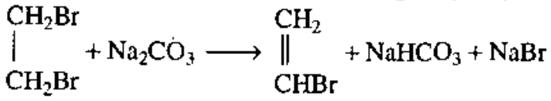
(1) From ethylene dibromide (Laboratory method) :

When ethylene dibromide is heated with moist silver oxide or aqueous solution of sodium carbonate, ethylene glycol is formed.



$$\begin{array}{l} CH_2Br \\ | \\ CH_2Br \end{array} + Na_2CO_3 + 2H_2O \xrightarrow{\Delta} \begin{array}{l} CH_2OH \\ | \\ CH_2OH \end{array} + 2NaBr + CO_2$$

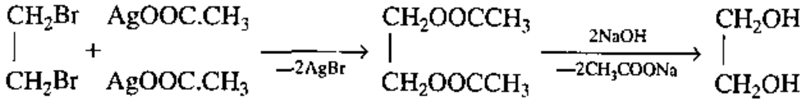
The yield is poor by this method because of side reaction giving vinyl bromide.



$$\begin{array}{l} CH_2Br \\ | \\ CH_2Br \end{array} + Na_2CO_3 \longrightarrow \begin{array}{l} CH_2 \\ \| \\ CHBr \end{array} + NaHCO_3 + NaBr$$

Vinyl bromide

NaOH or KOH are not used for hydrolysis as they also give vinyl bromide. For better yields, ethylene dibromide is first converted to ethylene diacetate. The diacetate on hydrolysis with dilute sodium hydroxide gives ethylene glycol.



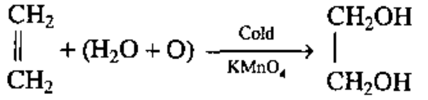
$$\begin{array}{l} CH_2Br \\ | \\ CH_2Br \end{array} + \begin{array}{l} AgOOC.CH_3 \\ \\ AgOOC.CH_3 \end{array} \xrightarrow[-2AgBr]{} \begin{array}{l} CH_2OOCCH_3 \\ | \\ CH_2OOCCH_3 \end{array} \xrightarrow[-2CH_3COONa]{2NaOH} \begin{array}{l} CH_2OH \\ | \\ CH_2OH \end{array}$$

Silver acetate
(2 moles)

Ethylene diacetate

Ethylene glycol

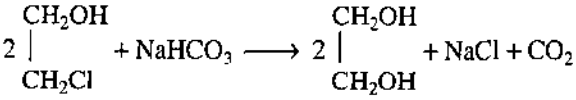
(2) From ethylene : By oxidation of ethylene with cold dil. $KMnO_4$ solution.



$$\begin{array}{l} CH_2 \\ \| \\ CH_2 \end{array} + (H_2O + O) \xrightarrow[KMnO_4]{Cold} \begin{array}{l} CH_2OH \\ | \\ CH_2OH \end{array}$$

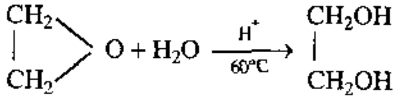
Ethylene glycol

(3) From ethylene chlorohydrin : By the hydrolysis of ethylene chlorohydrin with $NaHCO_3$.



$$2\begin{array}{l} CH_2OH \\ | \\ CH_2Cl \end{array} + NaHCO_3 \longrightarrow 2\begin{array}{l} CH_2OH \\ | \\ CH_2OH \end{array} + NaCl + CO_2$$

(4) From ethylene oxide : By the hydrolysis of ethylene oxide with H_2O at 200°C under pressure or with dil. H_2SO_4 at 60°C (Commercial method).



$$\begin{array}{l} CH_2 \\ | \\ CH_2 \end{array}\!\!\!> O + H_2O \xrightarrow[60°C]{H^+} \begin{array}{l} CH_2OH \\ | \\ CH_2OH \end{array}$$

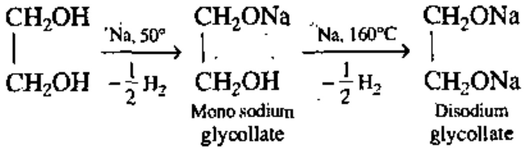
[II] Physical Properties of Ethylene Glycol

Glycol is a colourless viscous liquid, B.P. 197°C. It has a sweet taste. It is miscible with water and ethanol in all proportions but is insoluble in ether.

[III] Chemical Properties of Ethylene Glycol

Glycol contains two primary alcoholic groups. Its chemical reactions are, therefore, those of primary alcohols twice over.

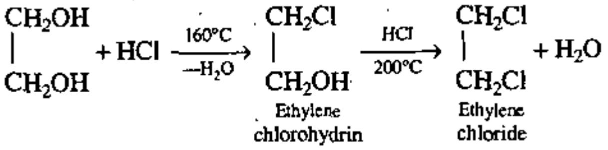
(1) Action of sodium : Mono and disodium glycollate are formed and hydrogen gas is evolved.



$$\begin{array}{c}CH_2OH\\|\\CH_2OH\end{array}\xrightarrow[-\frac{1}{2}H_2]{Na,\ 50^\circ}\begin{array}{c}CH_2ONa\\|\\CH_2OH\\\text{Mono sodium}\\\text{glycollate}\end{array}\xrightarrow[-\frac{1}{2}H_2]{Na,\ 160^\circ C}\begin{array}{c}CH_2ONa\\|\\CH_2ONa\\\text{Disodium}\\\text{glycollate}\end{array}$$

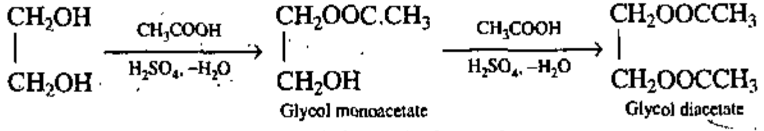
(2) Action of acids : Esters are formed.

(a) With HCl : Ethylene chlorohydrin and ethylene chloride are formed.



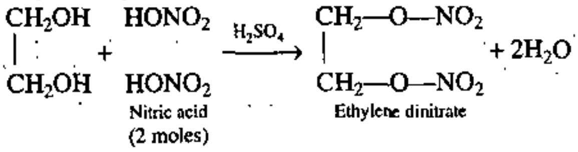
$$\begin{array}{c}CH_2OH\\|\\CH_2OH\end{array}+HCl\xrightarrow[-H_2O]{160^\circ C}\begin{array}{c}CH_2Cl\\|\\CH_2OH\\\text{Ethylene}\\\text{chlorohydrin}\end{array}\xrightarrow[200^\circ C]{HCl}\begin{array}{c}CH_2Cl\\|\\CH_2Cl\\\text{Ethylene}\\\text{chloride}\end{array}+H_2O$$

(b) With CH_3COOH : Mono and diacetate are formed.



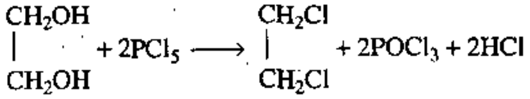
$$\begin{array}{c}CH_2OH\\|\\CH_2OH\end{array}\xrightarrow[H_2SO_4,\ -H_2O]{CH_3COOH}\begin{array}{c}CH_2OOC.CH_3\\|\\CH_2OH\\\text{Glycol monoacetate}\end{array}\xrightarrow[H_2SO_4,\ -H_2O]{CH_3COOH}\begin{array}{c}CH_2OOCCH_3\\|\\CH_2OOCCH_3\\\text{Glycol diacetate}\end{array}$$

(c) With conc. HNO_3 : Ethylene dinitrate is formed.

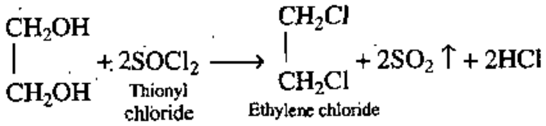


$$\begin{array}{c}CH_2OH\\|\\CH_2OH\end{array}+\begin{array}{c}HONO_2\\\\HONO_2\\\text{Nitric acid}\\\text{(2 moles)}\end{array}\xrightarrow{H_2SO_4}\begin{array}{c}CH_2—O—NO_2\\|\\CH_2—O—NO_2\\\text{Ethylene dinitrate}\end{array}+2H_2O$$

(3) Action of PCl_5 and $SOCl_2$: Ethylene chloride is formed.

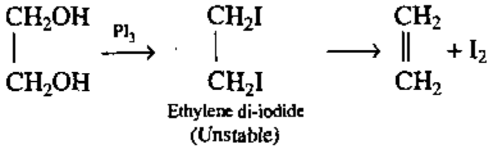


$$\begin{array}{c}CH_2OH\\|\\CH_2OH\end{array}+2PCl_5\longrightarrow\begin{array}{c}CH_2Cl\\|\\CH_2Cl\end{array}+2POCl_3+2HCl$$



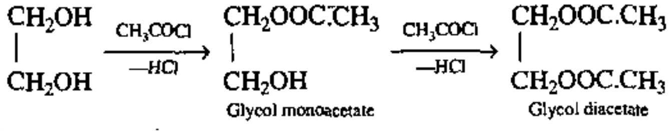
$$\begin{array}{c}CH_2OH\\|\\CH_2OH\end{array}+\begin{array}{c}2SOCl_2\\\text{Thionyl}\\\text{chloride}\end{array}\longrightarrow\begin{array}{c}CH_2Cl\\|\\CH_2Cl\\\text{Ethylene chloride}\end{array}+2SO_2\uparrow+2HCl$$

With PBr_3, glycol gives ethylene bromide, but with PI_3, ethylene di-iodide is formed which is unstable and is converted to ethylene and iodine.



$$\begin{array}{c}CH_2OH\\|\\CH_2OH\end{array}\xrightarrow{PI_3}\begin{array}{c}CH_2I\\|\\CH_2I\\\text{Ethylene di-iodide}\\\text{(Unstable)}\end{array}\longrightarrow\begin{array}{c}CH_2\\\|\\CH_2\end{array}+I_2$$

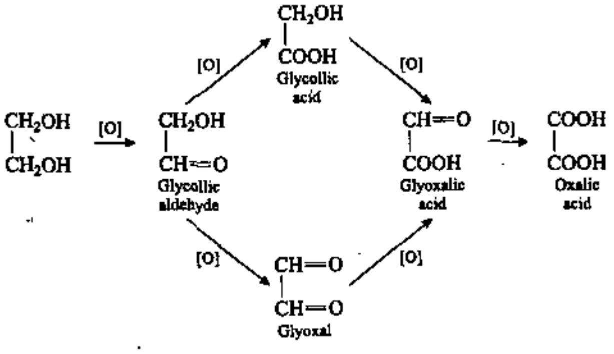
(4) Acetylation : With acetyl chloride or acetic anhydride, glycol produces glycol mono and diacetates.



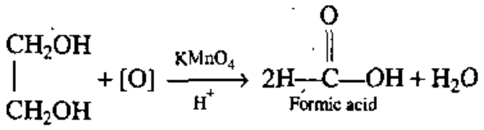
$$\begin{array}{c}CH_2OH\\|\\CH_2OH\end{array}\xrightarrow[-HCl]{CH_3COCl}\begin{array}{c}CH_2OOC.CH_3\\|\\CH_2OH\\\text{Glycol monoacetate}\end{array}\xrightarrow[-HCl]{CH_3COCl}\begin{array}{c}CH_2OOC.CH_3\\|\\CH_2OOC.CH_3\\\text{Glycol diacetate}\end{array}$$

(5) Oxidation :

(a) The oxidation of ethylene glycol with HNO_3 yields a number of substances as one or both the primary —OH groups may be oxidised first to aldehydes and then to carboxylic groups. The final product is oxalic acid.

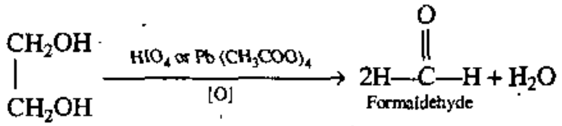


(b) Oxidation with acidic $KMnO_4$: Formic acid is formed.



$$\begin{matrix} CH_2OH \\ | \\ CH_2OH \end{matrix} + [O] \xrightarrow[H^+]{KMnO_4} \underset{\text{Formic acid}}{2H{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}OH} + H_2O$$

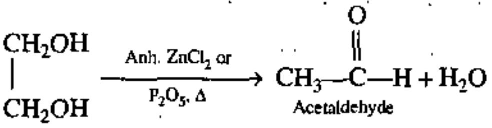
(c) Oxidation with periodic acid or lead tetra-acetate : Formaldehyde is formed.



$$\begin{matrix} CH_2OH \\ | \\ CH_2OH \end{matrix} \xrightarrow[{[O]}]{HIO_4 \text{ or } Pb(CH_3COO)_4} \underset{\text{Formaldehyde}}{2H{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}H} + H_2O$$

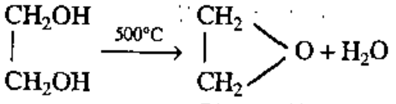
(6) Dehydration :

(a) When heated with anhydrous $ZnCl_2$ or P_2O_5, glycol gives acetaldehyde.



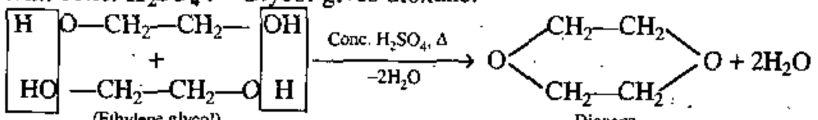
$$\begin{matrix} CH_2OH \\ | \\ CH_2OH \end{matrix} \xrightarrow[P_2O_5,\ \Delta]{\text{Anh. } ZnCl_2 \text{ or}} \underset{\text{Acetaldehyde}}{CH_3{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}H} + H_2O$$

(b) When heated alone at 500°C, glycol gives ethylene oxide.



Ethylene oxide

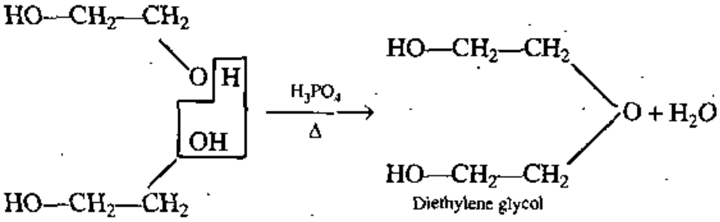
(c) With conc. H_2SO_4 : Glycol gives dioxane.



(Ethylene glycol)
(2 moles)

Dioxane
(Cyclic diether)

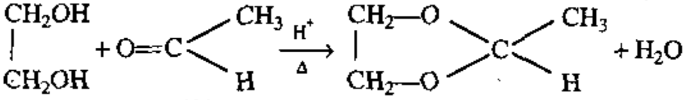
(d) With H_3PO_4 : Glycol gives diethylene glycol.



Diethylene glycol

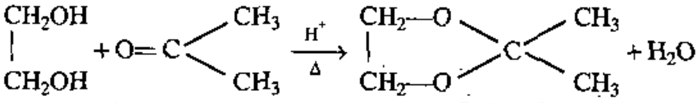
Ethylene glycol
(2 moles)

(7) Reaction with carbonyl compounds : Glycols forms cyclic compounds.



Acetaldehyde

Cyclic acetal



Acetone

Cyclic ketal

[IV] Uses of Ethylene Glycol

Glycol is used :

(i) As a preservative.

(ii) Nitroglycol is used as an explosive.

(iii) As a lubricant.

(iv) As a solvent in spirit wicks.

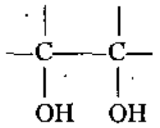
[V] Constitution of Ethylene Glycol

(1) The molecular formula of ethylene glycol is $C_2H_6O_2$.

(2) Presence of two hydroxyl groups : The reaction of glycol with Na, CH_3COCl and PCl_5, indicates the presence of two hydroxyl groups in it.

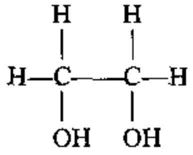
$$C_2H_4(OH)_2 + 2Na \longrightarrow C_2H_4O_2Na_2 + H_2$$
$$C_2H_4(OH)_2 + 2PCl_5 \longrightarrow C_2H_4Cl_2 + 2POCl_3 + 2HCl$$
$$C_2H_4(OH)_2 + 2CH_3COCl \longrightarrow C_2H_4(OCOCH_3)_2 + 2HCl$$

Since ethylene glycol is a stable compound, the two —OH groups must be attached to different carbon atoms as shown below :



$$\begin{array}{cc} | & | \\ -C- & -C- \\ | & | \\ OH & OH \end{array}$$

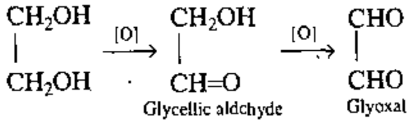
(3) Keeping in view the tetravalency of carbon, monovalency of hydrogen and bivalency of oxygen, glycol may be written as :



$$\begin{array}{ccc} & H & H \\ & | & | \\ H- & C- & C-H \\ & | & | \\ & OH & OH \end{array}$$

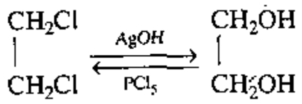
(4) Confirmation :

(i) On oxidation, glycol first gives glycollic aldehyde and then glyoxal which confirms the presence of *two primary alcoholic groups.*



$$\begin{array}{c} CH_2OH \\ | \\ CH_2OH \end{array} \xrightarrow{[O]} \underset{\text{Glycellic aldehyde}}{\begin{array}{c} CH_2OH \\ | \\ CH{=}O \end{array}} \xrightarrow{[O]} \underset{\text{Glyoxal}}{\begin{array}{c} CHO \\ | \\ CHO \end{array}}$$

(ii) *Ethylene chloride on hydrolysis with moist silver oxide gives* glycol which on treatment with PCl_5 gives back ethylene chloride.



$$\begin{array}{c} CH_2Cl \\ | \\ CH_2Cl \end{array} \underset{PCl_5}{\overset{AgOH}{\rightleftharpoons}} \begin{array}{c} CH_2OH \\ | \\ CH_2OH \end{array}$$

• 1.10. GLYCEROL

[I] Manufacture of Glycerol

Glycerol is manufactured by the following methods.

(a) From oils and fats, (b) By fermentation of sugars.

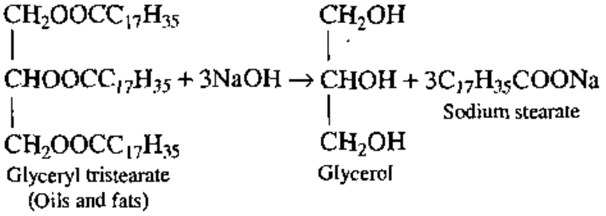
(1) From Oils and Fats : Oils and fats are the triesters of glycerol with higher fatty acids like stearic acid ($C_{17}H_{35}COOH$), palmitic acid ($C_{15}H_{31}COOH$) and oleic acid ($C_{17}H_{33}COOH$). On hydrolysis, they give glycerol and fatty acids. These fatty acids find use in industry for the manufacture of candles or soaps in the form of sodium or potassium salts. The oils and fats are hydrolysed either :

(a) by alkali in soap industry.

or (b) by superheated steam in candle industry.

In both these industries, glycerol is obtained as a by-product.

(a) Glycerol from spent lye of soap industry : In soap industry, oils and fats are hydrolysed with caustic alkali solution (lye) when glycerol and sodium salts of fatty acids (soaps) are formed.



$$\underset{\substack{\text{Glyceryl tristearate} \\ \text{(Oils and fats)}}}{\begin{array}{l} CH_2OOCC_{17}H_{35} \\ | \\ CHOOCC_{17}H_{35} \\ | \\ CH_2OOCC_{17}H_{35} \end{array}} + 3NaOH \rightarrow \underset{\text{Glycerol}}{\begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}} + \underset{\text{Sodium stearate}}{3C_{17}H_{35}COONa}$$

The soap is salted out (or precipitated) by adding sodium chloride to the reaction product. The filterate obtained after filtering out the soap is known as ***spent lye.*** Spent lye contains 3–5% glycerol, unspent alkali, fatty acids, proteinous matter and colouring matter. Glycerol is recovered from it as given below :

(i) The spent lye is allowed to settle in a tank where most of the suspended impurities settle down.

(ii) The clear liquid is decanted to another tank, known as ***treating tank*** fitted with steam coils. It is treated with dilute HCl to neutralise about three-fourth of the free alkali present in the lye. It is now treated with alum or basic ferric sulphate which neutralises the remaining alkali and also converts the traces of sodium soaps as well as the free acids still present into insoluble iron soaps. A gelatinous precipitate of $Fe(OH)_3$ and insoluble iron soaps are formed.

$$6NaOH + Fe_2(SO_4)_3 \longrightarrow 2Fe(OH)_3 \downarrow + 3Na_2SO_4$$

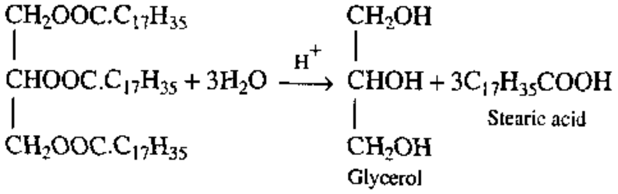
$$6C_{17}H_{35}COONa + Fe_2(SO_4)_3 \longrightarrow \underset{\text{Iron soap}}{2(C_{17}H_{35}COO)_3Fe} \downarrow + 3Na_2SO_4$$

(iii) The liquid along with the precipitate is filtered through filter press under pressure. The clear liquid so obtained is then concentrated under vacuum, when most of NaCl separates out. At this stage, a coloured solution is obtained which contains 80% glycerol (crude glycerol).

(iv) The crude glycerol so obtained is now decolourised by boiling with animal charcoal. After filteration it is subjected to vacuum distillation by heating with superheated steam.

(v) The distillate containing water is then concentrated in vacuum pans until the specific gravity of glycerol becomes 1.29. It is 99.9% pure.

(b) Glycerol from the sweet water of candle industry : Candles are prepared from a mixture of wax and stearic acid. The stearic acid needed for this purpose is obtained by the hydrolysis of fats and oils with superheated steam using dilute H_2SO_4 as a catalyst. These fatty acids are usually solids which are removed by filteration.



$$\begin{array}{l} CH_2OOC.C_{17}H_{35} \\ | \\ CHOOC.C_{17}H_{35} + 3H_2O \\ | \\ CH_2OOC.C_{17}H_{35} \end{array} \xrightarrow{H^+} \underset{\text{Glycerol}}{\begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}} + \underset{\text{Stearic acid}}{3C_{17}H_{35}COOH}$$

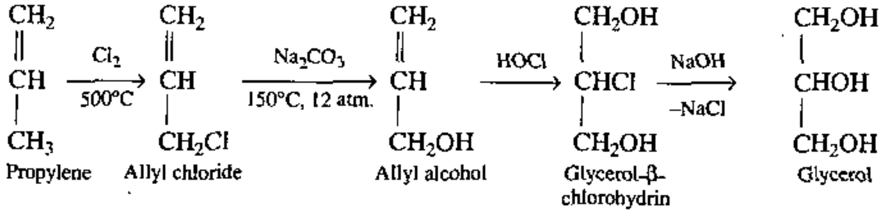
The filterate is known as ***sweet water.*** It contains glycerol, water and free fatty acids. It is neutralised with calculated amount of Na_2CO_3 and then subjected to steam distillation. Volatile fatty acids form non-volatile sodium salt which is left behind as residue. The distillate is a dilute solution of glycerol. It is first concentrated by evaporation of water under vacuum and then distilled and redistilled to obtain pure glycerol.

(2) By fermentation of sugars : During alcoholic fermentation of sugars about 3% glycerol is formed. Neuberg, a German chemist, observed that if the fermentation of sugars is carried out in presence of Na_2SO_3, the yield of glycerol can be increased upto 25%. The fermented liquid is then subjected to fractional distillation to obtain glycerol.

$$C_{12}H_{22}O_{11} \xrightarrow[+H_2O]{\text{Yeast}} \underset{\substack{\text{Glucose and}\\\text{fructose}}}{2C_6H_{12}O_6} \xrightarrow[\text{Yeast}]{Na_2SO_3} \underset{\text{Glycerol}}{C_3H_8O_3} + CH_3CHO + CO_2 + H_2O$$

[II] Glycerol From Synthetic Method

Glycerol can be prepared from propylene as follows :



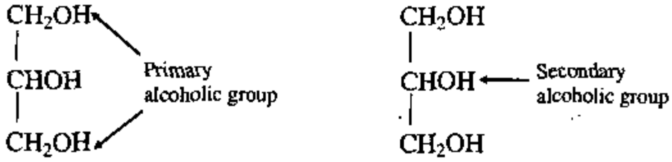
$$\underset{\text{Propylene}}{\begin{array}{c} CH_2 \\ \| \\ CH \\ | \\ CH_3 \end{array}} \xrightarrow[500°C]{Cl_2} \underset{\text{Allyl chloride}}{\begin{array}{c} CH_2 \\ \| \\ CH \\ | \\ CH_2Cl \end{array}} \xrightarrow[150°C,\ 12\ \text{atm.}]{Na_2CO_3} \underset{\text{Allyl alcohol}}{\begin{array}{c} CH_2 \\ \| \\ CH \\ | \\ CH_2OH \end{array}} \xrightarrow{HOCl} \underset{\substack{\text{Glycerol-}\beta\text{-}\\\text{chlorohydrin}}}{\begin{array}{c} CH_2OH \\ | \\ CHCl \\ | \\ CH_2OH \end{array}} \xrightarrow[-NaCl]{NaOH} \underset{\text{Glycerol}}{\begin{array}{c} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}}$$

[III] Physical Properties

Pure glycerol is a colourless, odourless, syrupy liquid, heavier than water. It is soluble in water or alcohol in all proportions, but insoluble in ether or chloroform. It is very hygroscopic. Its boiling point is 290°C.

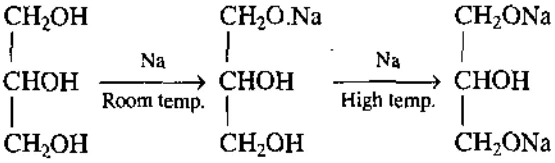
[IV] Chemical Properties

Glycerol contains two primary and one secondary alcoholic groups. Hence, it shows the properties of both primary and secondary alcohols.



$$\begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array} \qquad \begin{array}{l} CH_2OH \\ | \\ CHOH \longleftarrow \\ | \\ CH_2OH \end{array}$$

(1) With sodium : Glycerolates are formed.



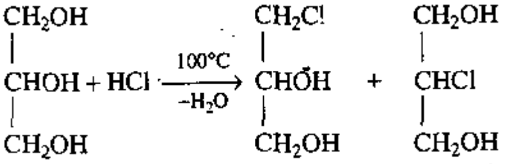
$$CH_2OH\text{–}CHOH\text{–}CH_2OH \xrightarrow[\text{Room temp.}]{Na} CH_2O.Na\text{–}CHOH\text{–}CH_2OH \xrightarrow[\text{High temp.}]{Na} CH_2ONa\text{–}CHOH\text{–}CH_2ONa$$

Monosodium glycerolate

Disodium glycerolate

(2) Reaction with acids :

(i) With HCl : At 110°C, a mixture of two mono derivatives is formed.

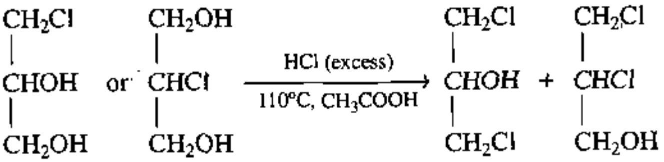


$$CH_2OH\text{–}CHOH\text{–}CH_2OH + HCl \xrightarrow[-H_2O]{100°C} CH_2Cl\text{–}CHOH\text{–}CH_2OH + CH_2OH\text{–}CHCl\text{–}CH_2OH$$

Glycerol α-chlorohydrin

Glycerol β-chlorohydrin

On further reaction at 110°C in presence of CH_3COOH, glycerol produces a mixture of two di-substituted derivatives.

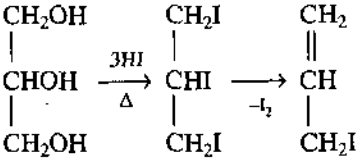


$$CH_2Cl\text{–}CHOH\text{–}CH_2OH \text{ or } CH_2OH\text{–}CHCl\text{–}CH_2OH \xrightarrow[110°C,\ CH_3COOH]{HCl\ (excess)} CH_2Cl\text{–}CHOH\text{–}CH_2Cl + CH_2Cl\text{–}CHCl\text{–}CH_2OH$$

α, α′ Glycerol dichlorohydrin

α, β Glycerol dichlorohydrin

(ii) With HI : When glycerol is treated with small amount of HI, allyl iodide is formed.

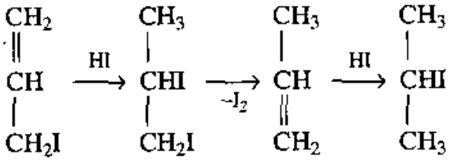


$$CH_2OH\text{–}CHOH\text{–}CH_2OH \xrightarrow[\Delta]{3HI} CH_2I\text{–}CHI\text{–}CH_2I \xrightarrow{-I_2} CH_2{=}CH\text{–}CH_2I$$

Glyceryl triodide (Unstable)

Allyl iodide

When HI is present in excess, allyl iodide first produced as above is reduced to propene. In presence of excess of HI, propene adds a molecule of HI to form 2–iodopropane (isopropyl iodide). *This addition occurs according to Markownikoff's rule.*



$$CH_2{=}CH\text{–}CH_2I \xrightarrow{HI} CH_3\text{–}CHI\text{–}CH_2I \xrightarrow{-I_2} CH_3\text{–}CH{=}CH_2 \xrightarrow{HI} CH_3\text{–}CHI\text{–}CH_3$$

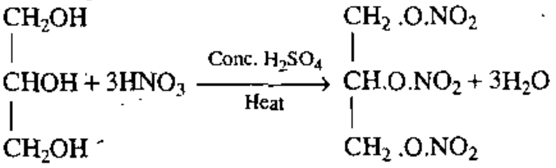
Allyl iodide

1, 2, -Diiodo propane (Unstable)

Propene

Isopropyl iodide

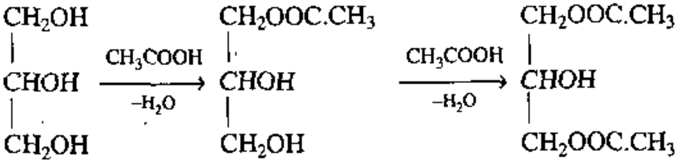
(iii) With HNO₃ : In presence of conc. H_2SO_4, glycerol forms glyceryl trinitrate (explosive).



$$CH_2OH\text{–}CHOH\text{–}CH_2OH + 3HNO_3 \xrightarrow[\text{Heat}]{\text{Conc. } H_2SO_4} CH_2.O.NO_2\text{–}CH.O.NO_2\text{–}CH_2.O.NO_2 + 3H_2O$$

Glyceryl trinitrate

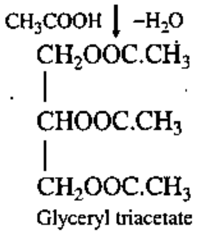
(iv) With CH₃COOH, (CH₃CO)₂O or CH₃COCl : Mono, di and triesters are formed.



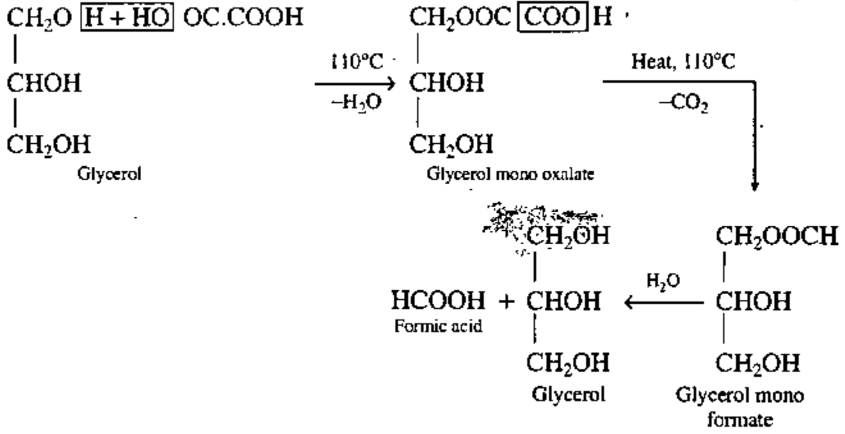
$$CH_2OH\text{–}CHOH\text{–}CH_2OH \xrightarrow[-H_2O]{CH_3COOH} CH_2OOC.CH_3\text{–}CHOH\text{–}CH_2OH \xrightarrow[-H_2O]{CH_3COOH} CH_2OOC.CH_3\text{–}CHOH\text{–}CH_2OOC.CH_3$$

Glyceryl monoacetate

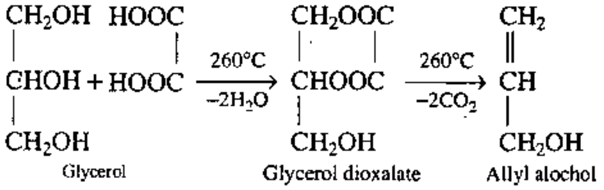
Glyceryl di-acetate



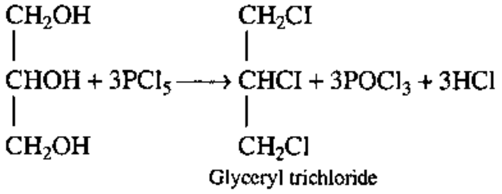
(v) With oxalic acid : (a) At 110°C and with excess of oxalic acid, formic acid is produced.



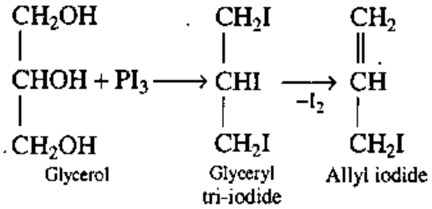
(b) At 260°C, allyl alcohol is formed.



(3) With PCl_5 or PCl_3 : Glycerol forms glyceryl trichloride.



(4) With PI_3 : Glycerol forms unstable glyceryl tri-iodide which decomposes to give allyl iodide.



(5) Oxidation : Glycerol contains two primary alcoholic and one secondary alcoholic groups and so on oxidation gives different products depending upon the nature of oxidising agents used. Theoretically, following products can be formed :

Oxidation with different reagents gives different products :

(i) Dil. HNO_3 gives glyceric acid and tartonic acid.

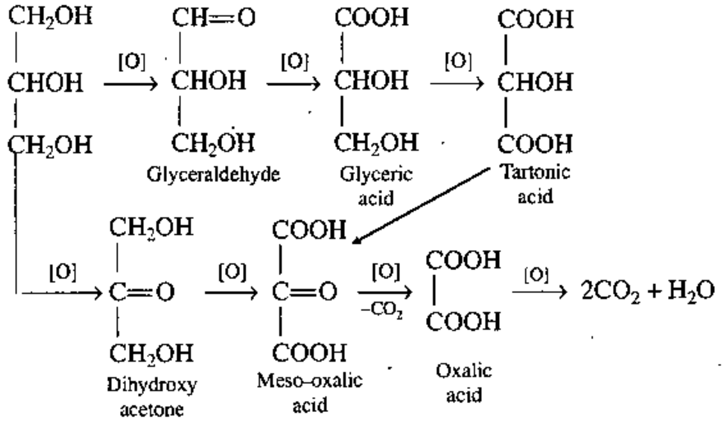
(ii) Conc. HNO_3 produces mainly glyceric acid.

(iii) Bismuth and sodium nitrate produce meso-oxalic acid.

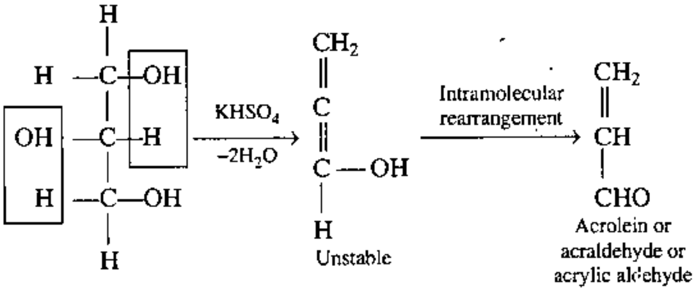
(iv) Fenton's reagent ($H_2O_2 + FeSO_4$) or NaOBr (sodium hypobromite) produces a mixture of glyceraldehyde and dihydroxy acetone, known as ***glycerose.***

(v) Bromine water in presence of Na_2CO_3 gives glyceraldehyde and dihydroxy acetone.

(vi) Acidic $KMnO_4$ gives CO_2 and H_2O.

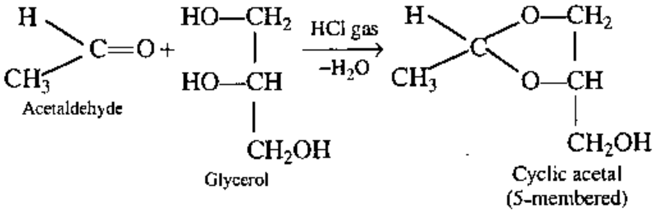


(6) Dehydration : Glycerol when heated alone or in presence of dehydrating agents like conc. H_2SO_4, P_2O_5, $KHSO_4$, or anhydrous $ZnCl_2$ produces acrolein or acraldehyde or acrylic aldehyde which has an offensive odour.

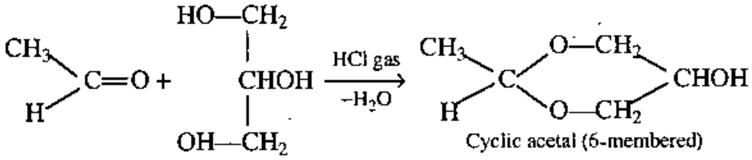


(7) Condensation with aldehydes and ketones : Glycerol gives cyclic acetals or cyclic ketals.

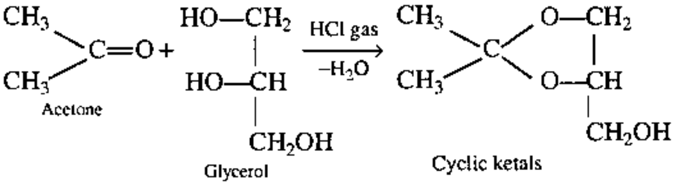
(a)



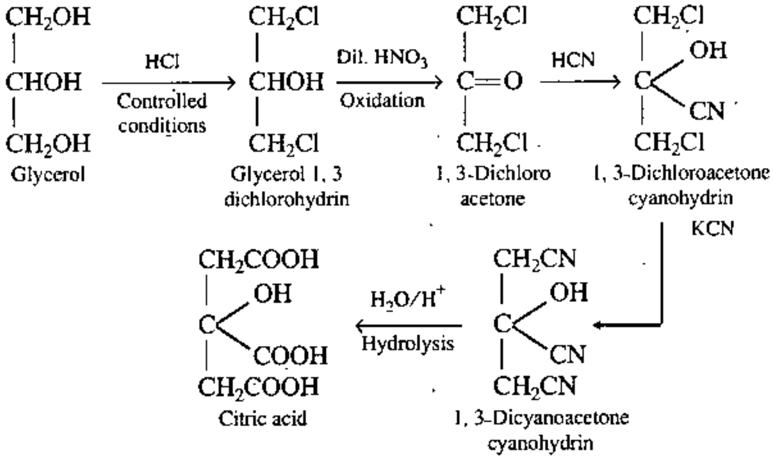
(b)



(c)



(8) Synthesis of citric acid : Citric acid is obtained from glycerol in the following steps:



[IV] Uses

Glycerol is used :

(i) As a sweetening agent in confectionary, beverages and medicines.

(ii) As antifreeze in automobile radiators.

(iii) In the preparation of non-drying inks, printing inks and stamp pad inks.

(iv) In the manufacture of proof cement.

(v) In the preparation of various compounds like formic acid, acrolein etc.

[V] Constitution

(i) Molecular formula : From analytical data the molecular formula of glycerol has been found to be $C_3H_8O_3$.

(ii) Nature of oxygen : The reactions of glycerol with acetyl chloride, nitric acid, PCl_5 etc. indicate that all the three oxygen atoms are present in the form of hydroxyl groups, *i.e.*, it contains 3 hydroxyl groups.

$$C_3H_8O_3 + 3CH_3COCl \longrightarrow \underset{\text{Glyceryl triacetate}}{C_3H_5\,(O.OC.CH_3)_3} + 3HCl$$

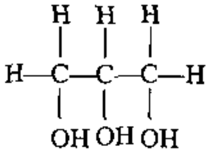
$$C_3H_8O_3 + 3HNO_3 \xrightarrow[H_2SO_4]{\text{Conc.}} \underset{\text{Glyceryl trinitrate}}{C_3H_5(O.NO_2)_3} + 3H_2O$$

$$C_3H_8O_3 + 3PCl_5 \longrightarrow \underset{\text{Glyceryl trichloride}}{C_3H_5Cl_3} + 3POCl_3 + 3HCl$$

Hence, glycerol may be written as $C_3H_5(OH)_3$.

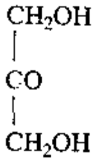
(iii) Attachment of three —OH groups at three different carbon atoms : As glycerol is a stable compound and moreover with acetyl chloride it gives mono, di and tri esters, it shows that all the three hydroxyl groups are linked to three different carbon atoms.

Keeping in view the tetracovalent, divalent, and monovalent nature of carbon, oxygen and hydrogen, respectively the following formula can be assigned to glycerol.



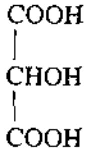
$$\begin{array}{ccccccc} & & H & & H & & H & \\ H & - & C & - & C & - & C & - & H \\ & & OH & & OH & & OH & \end{array}$$

(iv) Confirmation : (a) The above formula shows two primary and one secondary alcoholic groups which on oxidation forms dihydroxy acetone (I) and tartonic acid (II).



$$\begin{array}{c} CH_2OH \\ | \\ CO \\ | \\ CH_2OH \end{array}$$

Dihydroxy acetone (I)

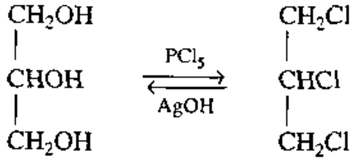


$$\begin{array}{c} COOH \\ | \\ CHOH \\ | \\ COOH \end{array}$$

Tartonic acid (II)

Structure (I) shows the presence of two primary alcoholic groups on the end carbon atoms and structure (II) indicates the presence of one secondary alcoholic group on the central carbon atom.

(b) With PCl_5, glycerol forms 1, 2, 3-trichloropropane which on hydrolysis with AgOH yields 1, 2, 3-trihydroxypropane, *i.e.*, glycerol.



$$\underset{\text{1,2, 3–Trihydroxypropane}}{\begin{array}{c} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}} \underset{AgOH}{\overset{PCl_5}{\rightleftarrows}} \underset{\text{1, 2, 3-Trichloropropane}}{\begin{array}{c} CH_2Cl \\ | \\ CHCl \\ | \\ CH_2Cl \end{array}}$$

Thus, glycerol is 1, 2, 3-trihydroxy propane.

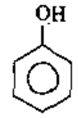
1.11. PHENOLS

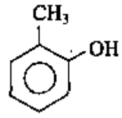
[I] Introduction and Nomenclature

Aromatic hydroxy compounds are obtained by the replacement of one or more hydrogen atoms of benzene or its homologues by hydroxyl (—OH) groups. This —OH group may be present in the nucleus or in side chain.

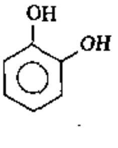
(I) —OH group in the nucleus : The compounds in which —OH group is directly attached to the benzene nucleus are called as *phenols*. These phenols may be monohydric, dihydric or trihydric depending upon the number of *—OH groups present.*

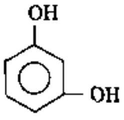
(a) Monohydric phenols : These contain one —OH group directly attached to the benzene nucleus. For example,

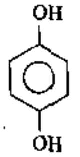

Phenol (carbolic acid)


o-Cresol (*o*-Methyl phenol)

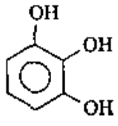
(b) Dihydric phenols : These contain two —OH groups directly attached to the benzene nucleus. For example,

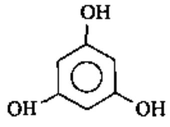

Catechol
(*o*-Dihydroxy benzene)

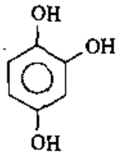

Resorcinol
(*m*-Dihydroxy benzene)


Hydroquinone or Quinol
(*p*-Dihydroxy benzene)

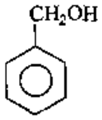
(c) Trihydric phenols : These contain three —OH groups directly attached to the benzene nucleus.


Pyrogallol
(1, 2, 3-trihydroxy benzene)


Phloroglucinol
(1, 3, 5-trihydroxy benzene)

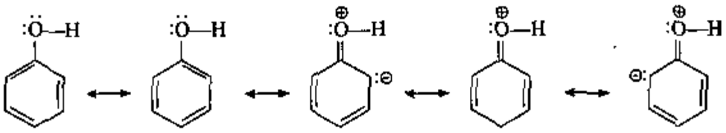

Hydroxy quinol
(1, 2, 4-trihydroxy benzene)

(II) —OH group in the side chain : The compounds containing —OH group in the side chain are known as aromatic *alcohols*. For example,


Benzyl alcohol

[II] Acidity of Phenols

Acidic nature of phenols : The acidic nature of phenols is due to their tendency to giv proton in solution. Their acidic nature can be explained on the basis of resonance. Phenol is resonance hybrid of the following forms :

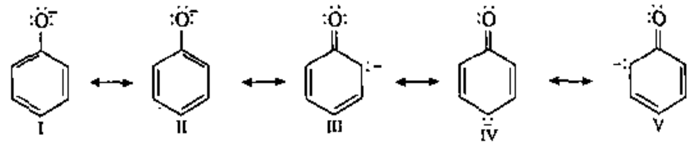


Due to resonance, oxygen atom acquires positive charge and it attracts the electron pair o O—H bond. Moreover, in phenol the —OH group is attached to phenyl group which has negativ inductive effect. This phenyl group also at tracts the electron pair of —O—H bond with the resul that the proton is removed easily and phenoxide ion attains stability due to resonance.

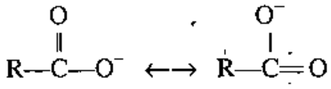
The resonance is not possible in alcohols. Hence, hydrogen atoms is firmly attached to oxygen As a result, alcohols are almost neutral.

Phenols are less aciidic than carboxylic acids. This is because that all the resonating form of phenoxide ion are not equivalent whereas both the resonating forms of carboxylate ion ar equivalent.

Resonating structures of phenoxide ion :



Resonating structures of carboxylate ion :

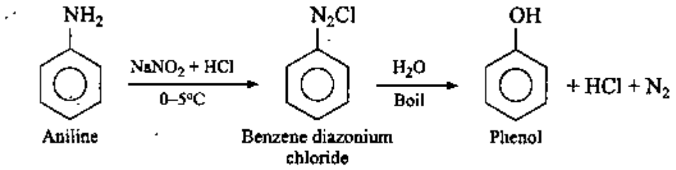


$$R{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}O^- \longleftrightarrow R{-}\overset{\overset{\displaystyle O^-}{|}}{C}{=}O$$

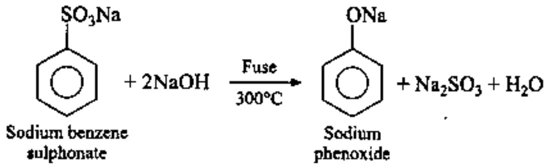
Hence, phenoxide ion is less stable than carboxylate ion. As a result, phenol is less acidic than carboxylic acid.

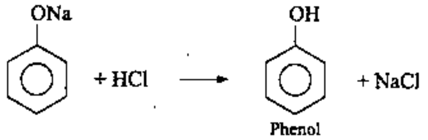
[III] General Methods for the Introduction of Hydroxyl Group Into Benzene Nucleus

(i) From aniline : Benzene diazonium chloride obtained by the diazotization of aniline, is boiled with water when phenol is formed.

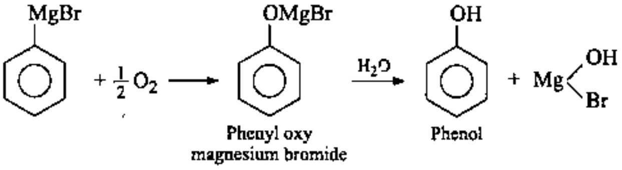


(ii) From benzene sulphonic acid : Sodium salt of the acid when fused with NaOH, gives sodium phenoxide which on treatment with mineral acid gives phenol.



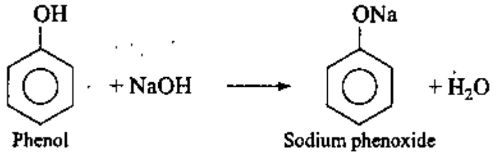


(iii) From Grignard's reagent : The oxidation of phenyl magnesium bromide and subsequent hydrolysis gives phenol.

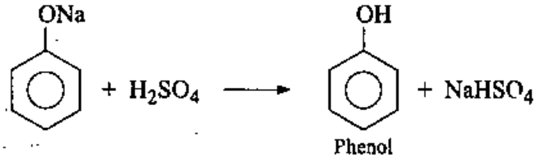


[IV] Manufacture of Phenol

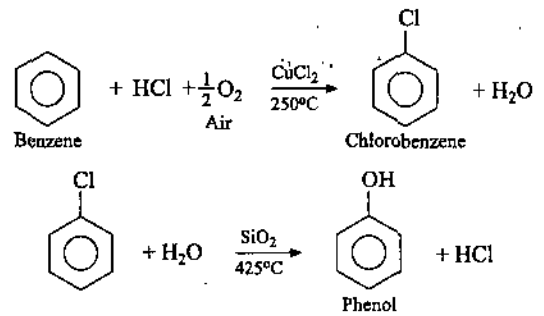
(i) From middle oil fraction : The middle oil fraction contains compounds like phenols, naphthalene and pyridine etc. This fraction is first of all cooled when naphthalene crystallizes out first. The remaining fraction is now treated with NaOH which dissolves phenol and its homologues.



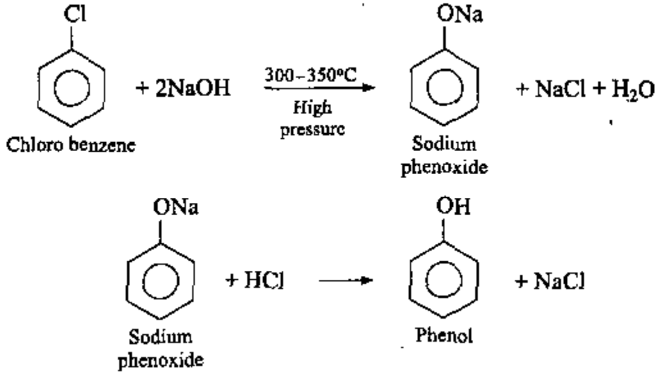
Now this solution is acidified with dil. H_2SO_4 which neutralizes the excess of NaOH and phenol separates out as a brown oily liquid. This is washed with water and fractionally distilled. The fraction distilling between 181–183°C is collected. It may still contain the impurity of *o*-cresol. Hence, it is cooled at 0°C, when phenol solidifies first.



(ii) Raschig process : This is the modern method for the preparation of phenol. In this method, vapours of benzene, air and HCl gas is passed over $CuCl_2$ catalyst heated to 250°C. The chlorobenzene so obtained is treated with steam at 425°C when phenol is obtained.



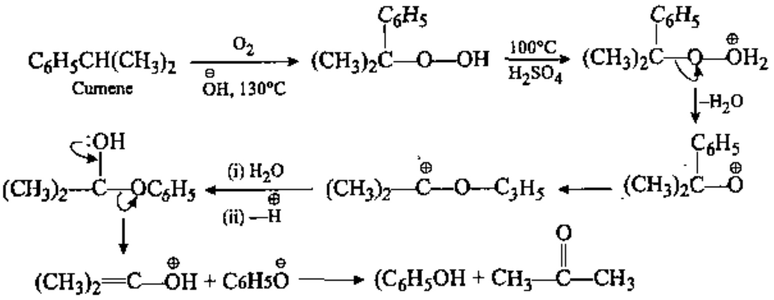
(iii) Dow's process : *Chlorobenzene when treated with 10% caustic soda solution at* 300–350°C and under high pressure in the presence of copper salt (catalyst), gives sodium phenoxide which on treatment with mineral acid gives phenol.



In the above reaction, some diphenyl ether is also formed, the formation of which can be checked by adding 10% diphenyl ether to the reaction mixture.

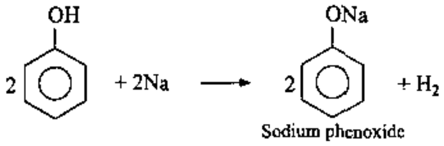
$$\underset{\text{Sodium phenoxide}}{C_6H_5O}\boxed{Na\ +\ Cl}\underset{\text{Chloro-benzene}}{C_6H_5} \longrightarrow \underset{\text{Diphenyl ether}}{C_6H_5{-}O{-}C_6H_5} + NaCl$$

(iv) From cumene : This is the most important commerical method for the preparation of phenol and is known as cumene-phenol process. In this method, cumene (isopropyl benzene) is oxidised to the hydroperoxide, which is then decomposed by acid into acetone and phenol.

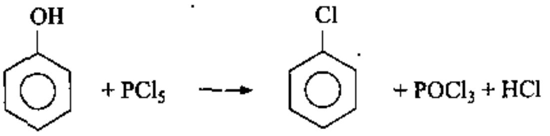


[I] Resemblance in Properties of Phenol with Alcohols

(i) Action with sodium : Sodium phenoxide is formed.



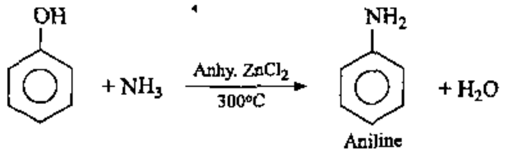
(ii) Action with PCl_5 : Chlorobenzene is formed.



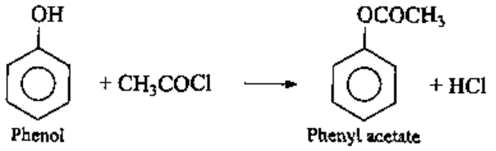
$POCl_3$ so formed reacts with excess of phenol to form triphenyl phosphate as the main product.

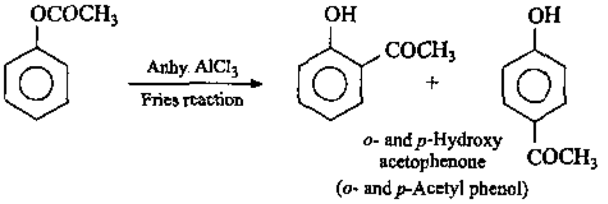
$$3C_6H_5OH + POCl_3 \longrightarrow \underset{\text{Triphenyl phosphate}}{(C_6H_5)_3PO_4} + 3HCl$$

(iii) Action with NH_3 : Aniline is formed.

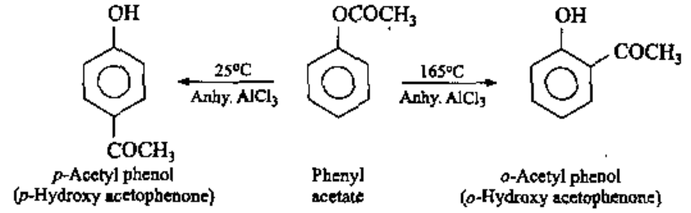


(iv) Acetylation : Phenol reacts with acetyl chloride to form phenyl acetate which on heating in presence of anhydrous $AlCl_3$ gives a mixture of *o*-and *p*-hydroxy ketones. ***(Fries reaction)***

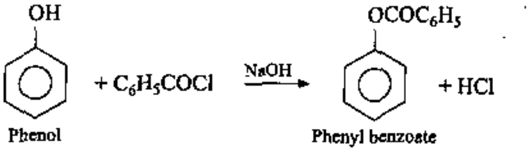




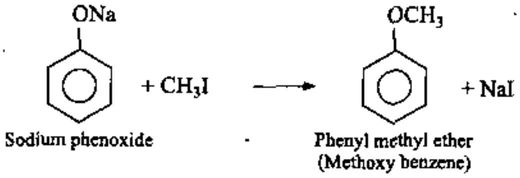
At 165°C, *o*-isomer and at 25°C, *p*-isomer is obtained as the main product.



(v) Benzoylation : Phenol reacts with benzoyl chloride in presence of NaOH to form phenyl benzoate. ***(Schotten-Baumann reaction)***

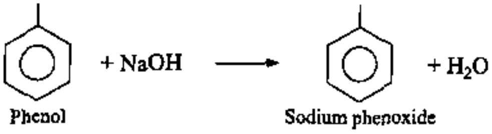


(vi) Action with alkyl halide : Sodium salt of phenol reacts with methyl iodide to form anisole (phenyl methyl ether or methoxy benzene)



[VI] Difference in Properties of Phenol from Alcohols

(i) Action with NaOH : Sodium phenoxide is formed.



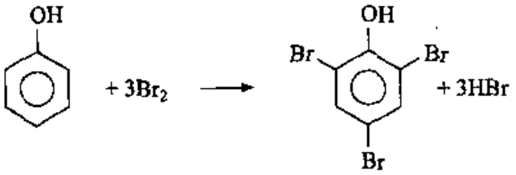
(ii) Action with zinc dust : Benzene is formed.

(iii) Action with $FeCl_3$ solution : Phenol reacts with 1% $FeCl_3$ solution to give violet solution.

$$6C_6H_5OH + FeCl_3 \longrightarrow [(C_6H_5O)_6Fe]^{3-} + 3H^+ + 3HCl$$

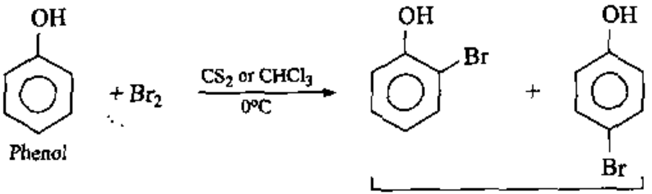
Hexa phenoxy iron (III) ion (violet solution)

(iv) Halogenation : *Phenol can be readily halogenated due to the strong o-and p-directive* influence of —OH group. With Br_2 water, it gives a white precipitate of 2, 4, 6 tribromo phenol.



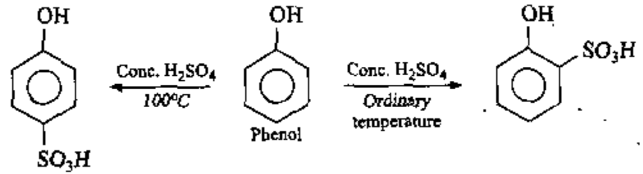
2, 4, 6-Tribromo phenol (White ppt.)

At low temperature and in presence of CS_2 or $CHCl_3$, phenol on controlled halogenation gives *mono halogen derivatives.*



o- & *p*-Bromo phenol

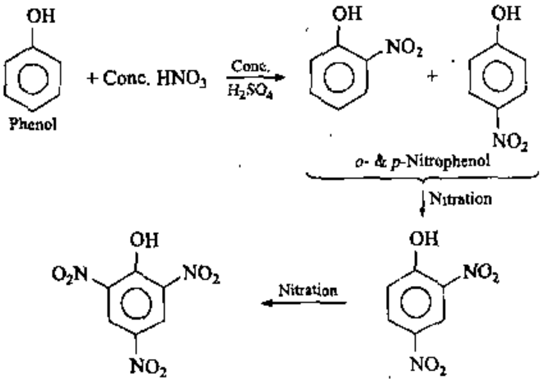
(v) Sulphonation : Phenol can be readily sulphonated. On treatment with conc. H_2SO_4 at room temperature, *o*-hydroxy benzene sulphonic acid and at 100°C, *p*-hydroxy benzene sulphonic acid is obtained as the main product.



p-Hydroxy benzene sulphonic acid

o-Hydroxy benzene sulphonic acid

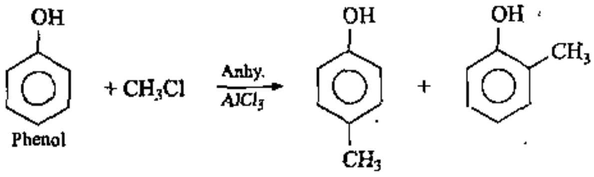
(vi) Nitration : On nitration with dil. HNO_3, *o*-and *p*-nitrophenol is obtained but on nitration with a mixture of conc. HNO_3 and conc. H_2SO_4, picric acid *is obtained in small amounts.*



2, 4, 6-Trinitrophenol (Picric acid)

2, 4-Dinitrophenol

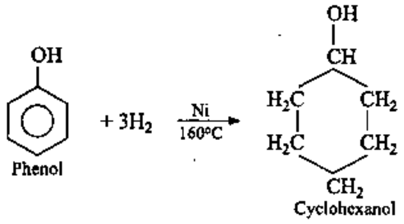
(vii) Friedel Crafts reaction : Phenol reacts with CH_3Cl in presence of anhydrous $AlCl_3$ to form *p*-cresol (main product) and *o*-cresol (less quantity).



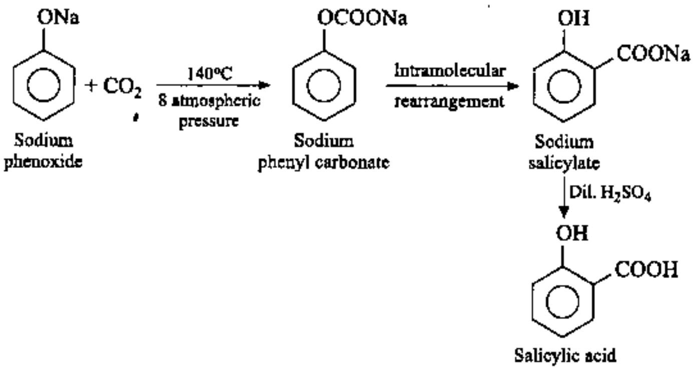
p-Cresol (Main product)

o-Cresol (Less quantity)

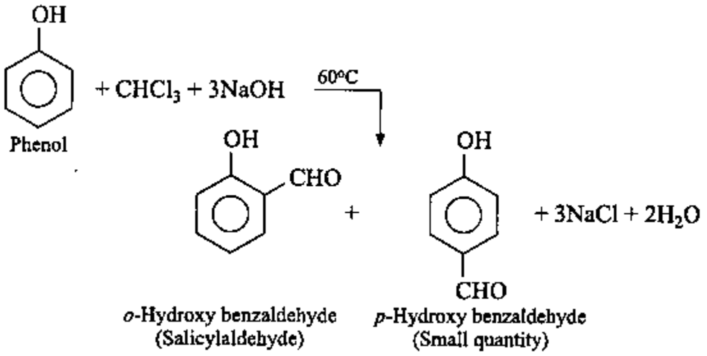
(viii) Hydrogenation : On hydrogenation in presence of nickel catalyst, phenol gives cyclohexanol.



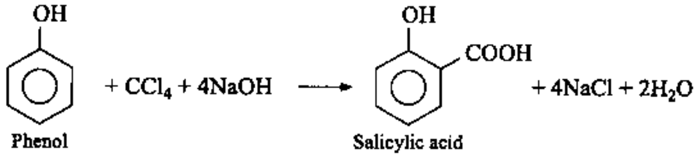
(ix) Kolbe-Schmidt reaction : Sodium salt of phenol reacts with CO_2 at 140°C and 8 atmospheric pressure to form sodium salicylate, which gives salicylic acid on treatment with dil. acid.



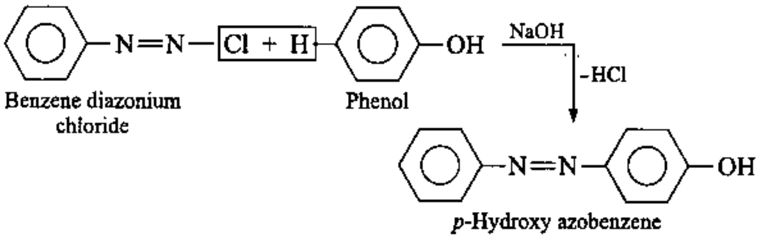
(x) Reimer–Tiemann reaction : Phenol reacts with $CHCl_3$ and NaOH at 60°C to form salicylaldehyde as the main product. *p*-Hydroxy benzaldehyde is obtained in small amounts.



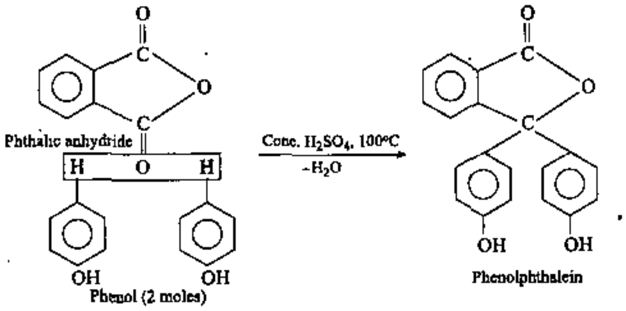
The use of CCl_4 in place of $CHCl_3$ gives salicylic acid as the main product.



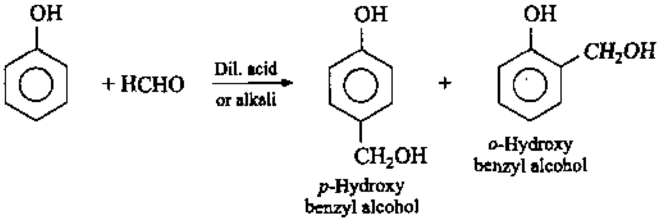
(xi) Coupling reaction : Phenol couples with benzene diazonium chloride at 0°C in presence of NaOH to form an azo dye.



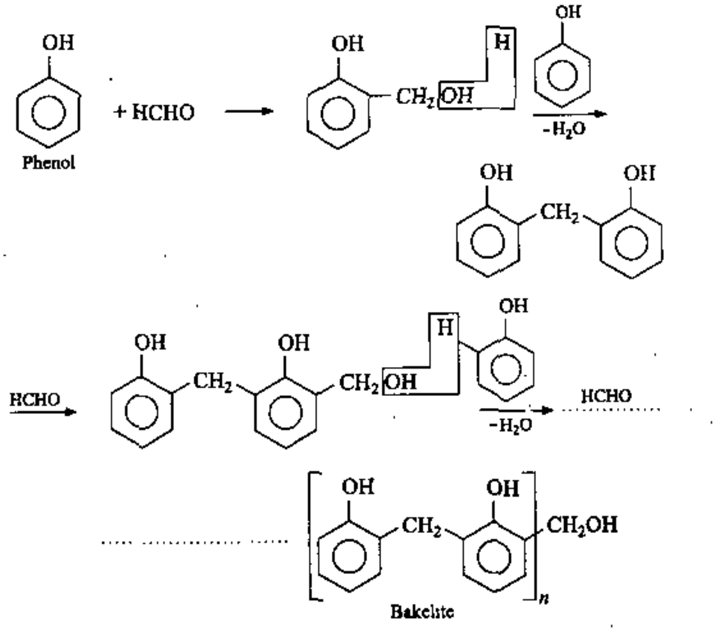
(xii) Phthalein reaction : Phenol on heating with phthalic anhydride in presence of conc. H_2SO_4 or anhydrous $ZnCl_2$ gives phenolphthalein which gives pink colour in alkaline solution.



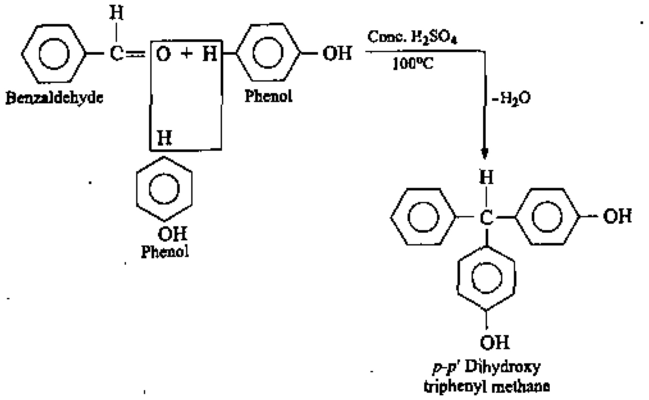
(xiii) Condensation reactions : Phenol reacts with aliphatic and aromatic aldehydes under different conditions to form different products. At low temperatures, it reacts with formalin (40% HCHO) in presence of dilute acid or alkali to form *p*-hydroxy benzyl alcohol (main product) and *o*-hydroxy benzyl alcohol (less quantity).



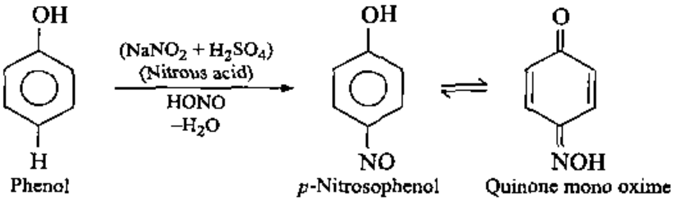
At high temperatures, phenol reacts with excess of HCHO in the presence of NH_3 to form *bakelite*.



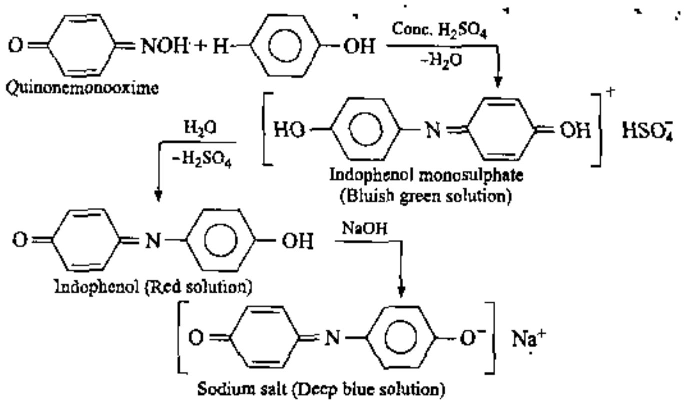
Phenol reacts with benzaldehyde in presence of conc. H_2SO_4 or anhydrous $ZnCl_2$ to form $p-p'$ dihydroxy triphenyl methane dye.



(xiv) Liebermann's nitroso reaction : Phenol on treatment with $NaNO_2$ and conc. H_2SO_4 first of all gives brown or red coloured substance which soon changes to bluish green. It becomes red on dilution with water and deep blue on treatment with NaOH. In this reaction first of all, a part of phenol reacts with HNO_2 ($NaNO_2$ + conc. H_2SO_4) to form *p*-nitroso phenol which is a tautomeric oxime of quinone.

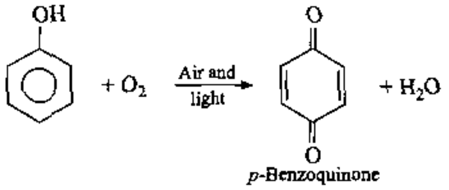


This mono oxime condenses with the remaining phenol in presence of conc. H_2SO_4 to form bluish green solution of indophenol monosulphate which becomes red on dilution with water. On treatment with NaOH, sodium salt of indophenol is formed which has deep blue colour.

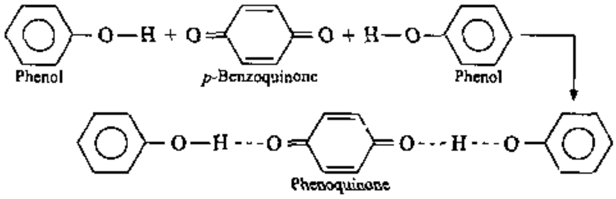


(xv) Oxidation : Phenol on oxidation gives different products under different conditions.

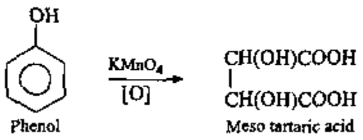
(i) It is slowly oxidized by atmospheric oxygen in presence of light to form pink solution.



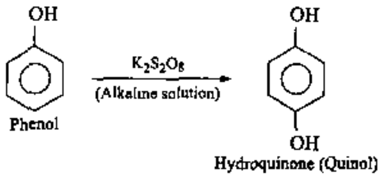
In this reaction, *p*-benzoquinone is first of all formed which reacts with more of phenol to form phenoquinone.



(ii) On oxidation with $KMnO_4$, mesotartaric acid is formed.



(iii) On oxidation with alkaline potassium peroxydisulphate, hydroquinone is formed.



[VIII] Tests of Phenol

(i) Phenol gives violet colouration with 1% $FeCl_3$ solution.

(ii) Phenol gives Liebermann's nitroso test.

(iii) Phenol reacts with phthalic anhydride in presence of conc. H_2SO_4 *to form* phenolphthalein which gives pink colour in dilute alkaline solution.

(iv) Phenol gives a white precipitate of 2, 4, 6-tribromo phenol with bromine water.

[IX] Uses of Phenol

Phenol is used :

(i) In the preparation of medicines such as salicylic acid, aspirin, phenacetin etc.

(ii) As an antiseptic and disinfectant in carbolic soaps and lotions.

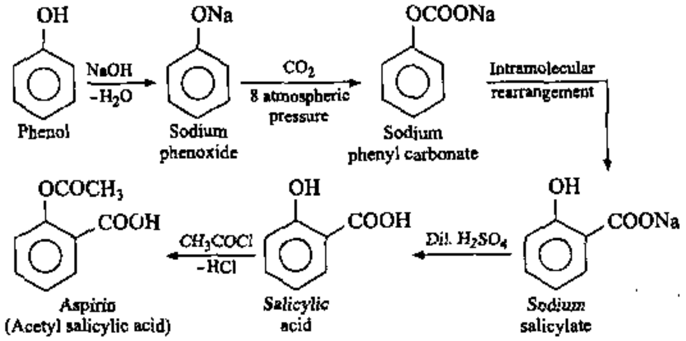
(iii) In the preparation of cyclohexanol which is used as a solvent.

(iv) In the preparation of bakelite (a resin), phenolphthalein (an indicator), picric acid (an explosive) and azo dyes.

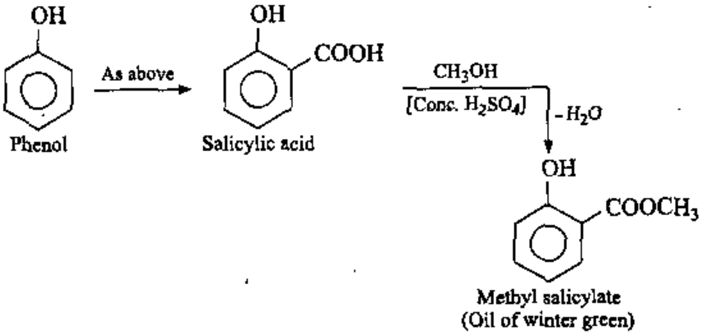
(v) In the preservation of ink.

• 1.12. INTERCONVERSIONS OF PHENOL

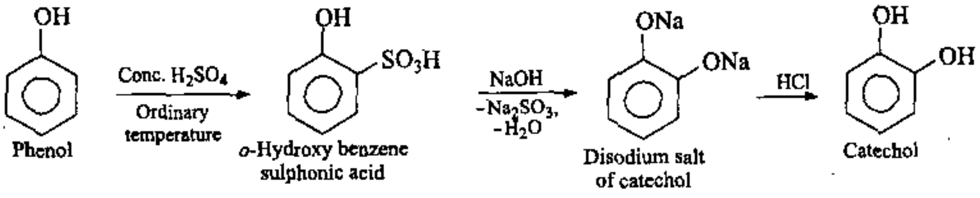
(i) Aspirin from phenol



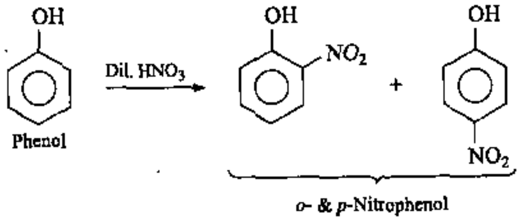
(ii) Oil of winter green from phenol



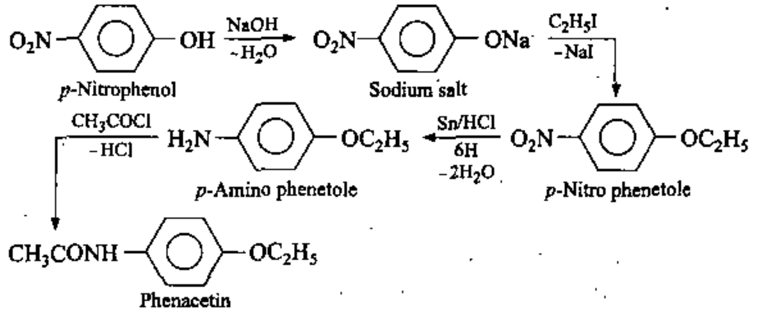
(iii) Catechol from phenol



(iv) *p*-Nitrophenol and phenacetin from phenol



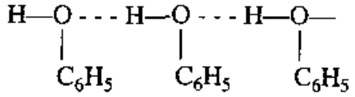
The mixture so obtained is steam distilled when *o*-isomer being volatile separates out leaving behind non-volatile *p*-isomer. From *p*-nitro phenol, phenacetin is obtained as follows :



1.13. EXPLANATION OF FACTS REGARDING PHENOLS

(i) Phenol has much higher boiling point than other compounds of comparable molecular weight.

Phenol has much higher boiling point than other compounds of comparable molecular weight, because hydrogen bonding is found in phenol molecules. This hydrogen bond is formed between oxygen atom of one molecule and hydrogen atom of another molecule.

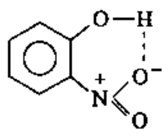


$$H{-}\underset{\underset{C_6H_5}{|}}{O}\cdots H{-}\underset{\underset{C_6H_5}{|}}{O}\cdots H{-}\underset{\underset{C_6H_5}{|}}{O}{-}$$

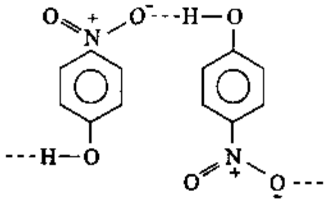
A large amount of energy is required for breaking these hydrogen bonds. Hence, phenol has much higher boiling point than other compounds of approximately same molecular weight.

(ii) o-Nitrophenol has lower boiling point than p-nitrophenol.

o-Nitrophenol has lower boiling point than its *p*-isomer. This is because in the case of *o*-nitrophenol, there is present intramolecular H-bonding, whereas in *p*-nitrophenol, there is present intermolecular H-bonding. Hence, in the case of *p*-nitrophenol, a greater amount of energy is required for breaking H-bonds.



o-Nitrophenol
(Intramolecular
H-bonding)



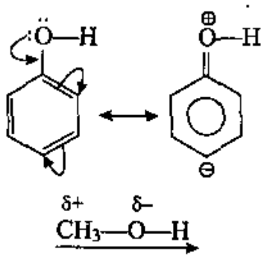
p-Nitrophenol
(Intermolecular
H-bonding)

(iii) Picric acid does not contain carboxylic group but it is acidic in nature.

Picric acid is 2, 4, 6, trinitrophenol. The acidic nature of phenolic compounds can be explained on the basis of resonance. (Please refer to problem 23 (a)). The presence of three electron withdrawing nitro groups result in increased resonance in the contributing structures and greater stability of the phenoxide ion. Hence, picric acid is even stronger acid than phenol.

(iv) Explain why dipole moments of phenol (1.7 D) and methanol (1.6 D) are in opposite directions ?

Delocalisation of electron density from oxygen to benzene ring makes the oxygen of phenol of be the positive and of the molecular dipole. In methanol, the strongly electron-withdrawing oxygen is the negative end of the dipole due to + *I* effect of the methyl group. So, the two dipoles act in opposite directions.

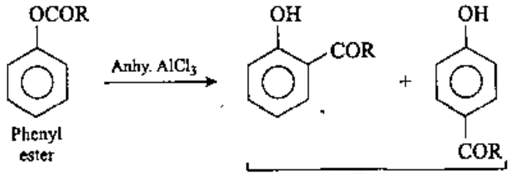


(v) Phenol is an acid, but does not react with sodium bicarbonate. Explain.

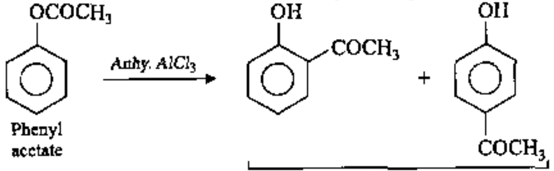
Phenol is a weaker acid than the carbonic acid (H_2CO_3), so it does not produce CO_2 by decomposing $NaHCO_3$, a salt of carbonic acid. A weaker acid cannot decompose a salt of stronger acid.

• 1.14. FRIES REARRANGEMENT

Tries rearrangement of phenyl ester into an *o*- or *p*-hydroxy ketone or both takes place in the presence of anhydrous $AlCl_3$. Thus, when phenyl ester is heated with anhydrous $AlCl_3$, the migration of acyl group from the side chain to the nucleus takes place.

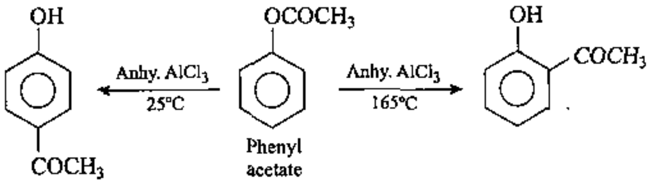


o- and *p*-Hydroxy ketones



o- and *p*-Hydroxy acetophenone

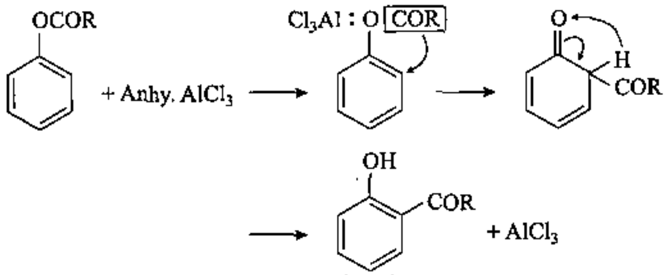
The migration of acyl group to *o*- and *p*-positions depends upon the experimental conditions and structure of the ester. In general, low temperature favours the formation of *p*-isomer and high temperature favours the formation of *o*-isomer.



p-Hydroxy acetophenone
(*p*-Acetyl phenol)

o-Hydroxy acetophenone
(*o*-Acetyl phenol)

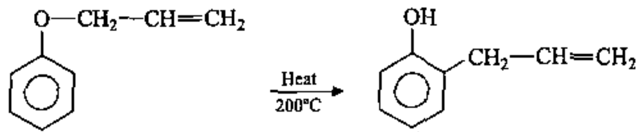
Mechanism : According to Baltzly (1956), the rearrangement takes place intramolecularly, *i.e.*, the formation of intermediate transition state takes place.



o-Hydroxy ketone

• 1.15. CLAISEN REARRANGEMENT

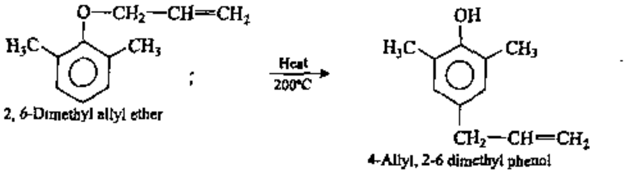
Claisen rearrangement involves the conversion of phenyl allyl ether to allyl phenols by means of heat. Thus, when phenyl allyl ether is heated at 200°C, isomerization takes place and the allyl group migrates to the ortho position of —OH group resulting in the formation of *o*-allyl phenol.



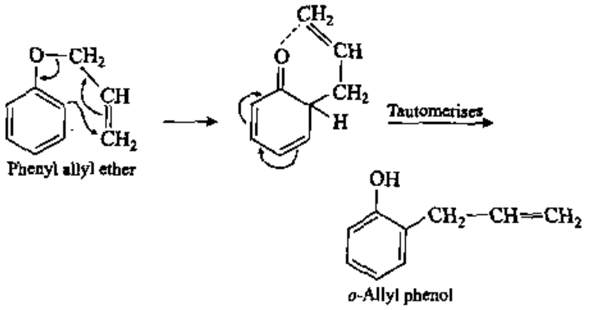
Phenyl allyl ether

o-Allyl phenol

If both the ortho positions are occupied, then migration takes place to the para position.



Mechanism : The mechanism of the reaction may be represented as :

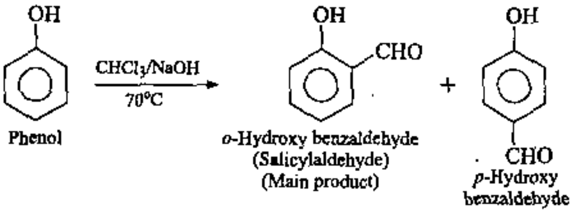


• 1.16. RIEMER-TIEMANN REACTION

Riemer-Tiemann reaction is a reaction for synthesising phenolic aldehydes and acids when heated with chloroform and alkali at 60°–70°C. On refluxing phenol and chloroform and sodium hydroxide, a formyl group (—CHO) is introduced into the benzene ring at *o*-position to —OH group. Small amounts of *p*-isomer is also obtained. The mixture can be separated by steam distillation, as only ortho isomer is steam volatile.

The use of CCl_4 in place of $CHCl_3$ leads to the formation of phenolic acid.

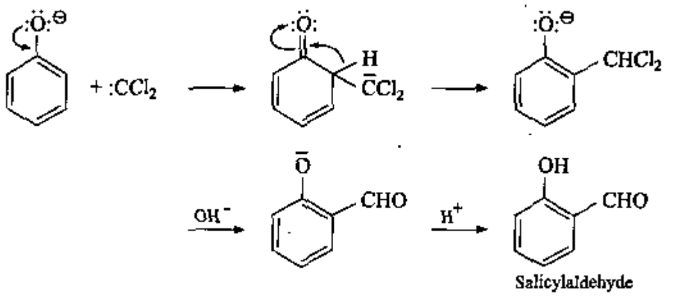
$$C_6H_5OH + CCl_4 + NaOH \longrightarrow \underset{\text{Phenolic acid}}{C_6H_4(OH)COOH} + 4NaCl + 2H_2O$$



Mechanism : This reaction shows *electrophilic substitution* of the aromatic substrate and the electrophile *dichlorocarbene*; $:CCl_2$ (carbon has only a sextet of elecrons) formed by the action of strong alkali on chloroform.

$$\bar{O}H + CHCl_3 \rightleftharpoons H_2O + :CCl_3^-$$

$$:\bar{C}Cl_3 \longrightarrow :CCl_2 + \bar{C}l$$



The *o*- and *p*-hydroxy benzoic acids are also obtained by similar reaction of alkali and CCl_4.

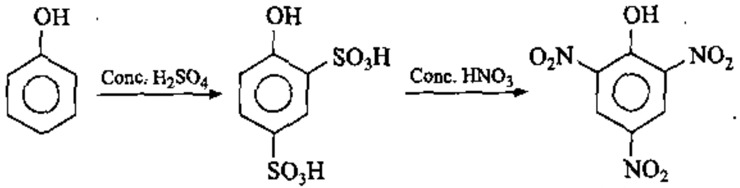
• 1.17. PICRIC ACID

[I] Preparation

(i) From symmetrical trinitrobenzene : Sym. trinitrobenzene on oxidation with potassium ferricyanide gives picric acid (Laboratory preparation).

Sym. trinitro benzene   Picric acid

(ii) From phenol : Phenol is first of all sulphonated and the resulting compound is then nitrated with picric acid is obtained. (Manufacture).

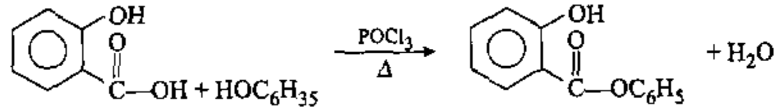


Phenol   Phenol *m*-disulphonic acid   Picric acid

[II] Properties

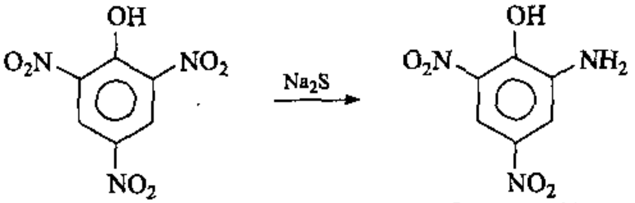
(i) Picric acid is a yellow crystalline solid, M. Pt. 122°C. It is insoluble in cold water but is soluble in hot water and either. It is stronger acid than phenol.

(ii) Action with PCl_5 : Picryl chloride is formed.



Salicylic acid   Phenol   *Phenyl salicylate (Salol)*

(iii) Reduction : On reduction with Na_2S, picramic acid is formed.



Picric acid   Picramic acid

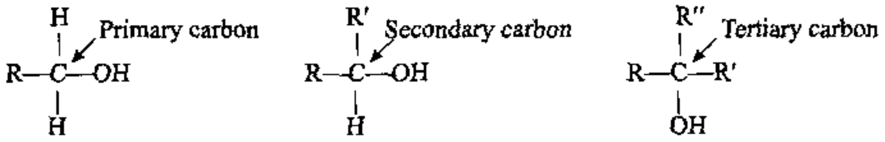
(iv) Formation of picrates : Picric acid forms *yellow, orange or red crystalline molecular* compounds known as *picrates* with aromatic hydrocarbons, phenols and amines.

[III] Uses

Pieric acid is used in the manufacture of explosives and as a dye for wool and silk. It is also used in the identification of aromatic hydrocarbons, phenols and amines.

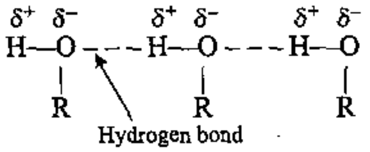
• SUMMARY

- Monohydric alcohols are classified as primary (1°), secondary (2°) or tertiary (3°) depending upon whether the —OH group is attached to a primary, a secondary or a tertiary carbon.



Primary alcohol   Secondary alcohol   Tertiary alcohol

- Boiling points of alcohols are much higher than those of the corrsponding alkanes, because of the presence of H-bonding in alcohols.

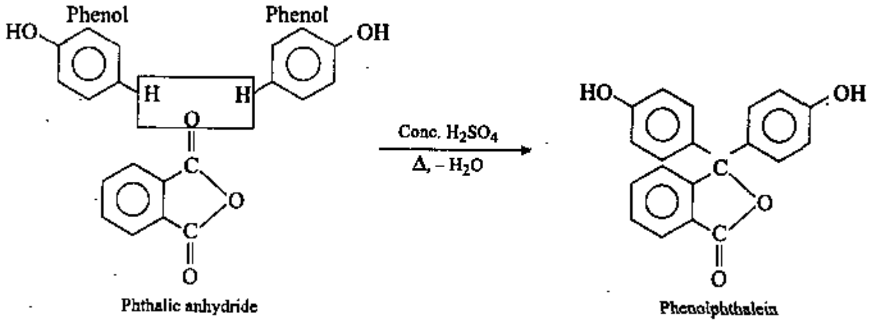


- 1°, 2° and 3° alcohols can be distinguished by Lucas test, dichromate test.

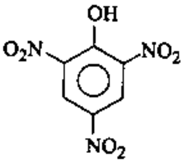
- Ethanol when warmed with aqueous KOH and iodine, gives yellow crystalline solid, iodoform (CHI_3).

$$CH_3CH_2OH + 4I_2 + 6KOH \xrightarrow{\text{Warm}} CHI_3 + COO^-K^+ + 5KI$$

- Ethylene glycol is used as an antifreeze for car radiators.
- Phenols are more acidic than alcohols but less so than carboxylic acids or even carbonic acid.
- Phenol reacts with phthalic anhydride in presence of sulphuric acid to form phenolphthalein (Pthalein reaction).



- Picric acid is trinitrophenol, *i.e.*,



2, 4, 6 Trinitrophenol

• STUDENT ACTIVITY

1. Give one test to distingiuish 1°, 2° and 3° alcohols.

2. Explain the dehydration of ethanol.

3. Show that glycerol has three hydroxyl groups.

4. What is Lucas test ?

5. Write a note on phthalein reaction.

6. What is Liebermann's nitroso reaction ?

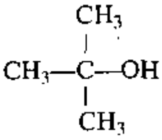
7. Write the structure of picric acid.

8. Write the mechanism of Riemer-Tiemann reaction.

• TEST YOURSELF

Answer the following questions :

1. How are alcohols prepared ? Describe their important reactions.
2. How is ethyl alcohol manufactured from molasses or starch ?
3. How does ethyl alcohol react with ?
   (a) Na (b) Conc. H_2SO_4/170°C (c) PCl_5 (d) $K_2Cr_2O_7/H^+$
4. How do primary, secondary and tertiary alcohols differ in their behaviour towards oxidation?
5. What happens when ethyl alcohol is treated with alkaline solution of iodine ?
6. How will you distinguish among primary, secondary and tertiary alcohols ?
7. How will you convert methyl alcohol into ethyl alcohol and vice versa ?
8. Explain why alcohols have higher boiling points than alkanes of comparable molecular weights?
9. Explain why ethanol has higher boiling point than diethyl ether ?
10. Rank the following compounds in increasing order of acidity and explain your answer.

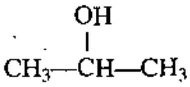


$CH_3-C(CH_3)_2-OH$

(A)

CH_3CH_2OH

(B)



$CH_3-CH(OH)-CH_3$

(C)

H_2O

(D)

11. How will you synthesise ethyl alcohol from acetylene ?
12. What is Lucas test ?
13. How is ethylene glycol prepared ?
14. How does ethylene glycol react with the following compounds ?
    (a) PCl_5 (b) PI_3 (c) Sodium (d) HIO_4
15. How is glycerol manufactured ?
16. How does glycerol react with the following compounds ?
    (a) $KHSO_4$/heat (b) HI (c) PCl_5 (d) Sodium
    (e) KNO_3/H_2SO_4 (f) Oxalic acid (g) Acetyl chloride
17. How is glycerol prepared from oils ?
18. Starting from glycerol, how will you obtain the following compounds ?
    (i) Nitroglycerine (ii) Allyl alcohol
    (iii) Isopropyl iodide (iv) Acrolein

19. Give the synthesis and uses of glycerol.

20. Describe the synthesis and uses of ethylene glycol.

21. What happens when ?

(i) Glycerol is heated with potassium hydrogen sulphate
(ii) Glycerol is treated with a mixture of conc. HNO_3 and H_2SO_4.
(iii) Glycerol is heated with oxalic acid at 260°C.
(iv) Ethylene glycol is distilled with a small amount of phosphoric acid ?

22. How will you synthesise the following compounds from ethylene glycol ?

(i) Oxalic acid (ii) Acetylene (iii) Dioxane

23. How will you synthesise succinic acid from ethylene glycol ?

24. How will you synthesise the following compounds from glycerol ?

(i) Allyl alcohol (ii) Nitroglycerine (iii) Acrolein

25. How will you synthesise glycerol from (i) propene and (ii) isopropyl alcohol ?

26. How is phenol prepared ? Mention any three methods.

27. What happens when ?

(i) Phenol is heated with zinc dust. (ii) Phenol is treated with bromine water.
(iii) Phenol is heated with CCl_4 in the presence of NaOH solution and then with dil HCl.

28. How does phenol react with the following compounds ?

(i) Zn/heat (ii) Br_2/H_2O (iii) HNO_3 (iv) Conc. H_2SO_4
(v) HNO_2 (vi) H_2/Ni (vii) Phthalic anhydride

29. How is picric acid prepared ?

30. How will you distinguish between phenol and ethyl alcohol ?

31. How will you distinguish between phenol and benzyl alcohol ?

32. Write a note an 'acicidty of phenols'.

33. Explain why phenol is more acidic than ethyl alcohol ?

34. Explain why *p*-nitrophenol is a stronger acid than phenol ?

35. Describe the mechanism of the following reactions :

(i) Fries rearrangement (ii) Claisen rearrangement (iii) Riemer-Tiemann reaction

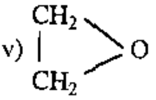
36. Write a note on Liebermann nitroso reaction.

37. What is iodoform test ?

38. Write a note on phthalein reaction.

39. Which one of the following will give tertiary alcohol by reacting with CH_3MgI ?

(i) HCHO (ii) CH_3CHO (iii) CH_3COCH_3 (iv)



40. A compound X known to be an alcohol of molecular formula $C_4H_{10}O$ on oxidation gives $C_4H_8O_2$. The compound X is most likely a :

(i) Primary alcohol (ii) Secondary alcohol (iii) Tertiary alcohol (iv) None of the above

41. The dehydration of glycol with anhydrous $ZnCl_2$ gives :

(i) Dioxane (ii) Acetaldehyde (iii) Diethylene glycol (iv) Ethylene dichloride

42. Which of the following compound is formed when glycerol is heated with oxalic acid at 370–380 K ?

(i) $CH_2{=}CH{-}CH_2OH$ (ii) HCOOH (iii) CH_3COOH (iv) $CH_2{=}CH{-}CHO$

43. Which of the following compound is formed when glycerol is heated with oxalic acid at 230°C ?

(i) HCOOH (ii) CH_3COOH (iii) $CH_2{=}CH{-}CH_2OH$ (iv) $CH_2{=}CH{-}CHO$

44. Which of the following compound is obtained when glycerol is heated with $KHSO_4$?

(i) Acrolein (ii) Allyl alcohol (iii) Glyceric acid (iv) Formic acid

45. Carbolic acid is :

(i) Phenol (ii) Salol (iii) Benzoic acid (iv) Aspirin

46. Phenol on distillaton with zinc dust gives :

(i) Benzene (ii) Toluene (iii) Benzaldehyde (iv) Benzoic acid

47. Which of the following gives blue colour with $FeCl_3$?

(i) Benzoic acid (ii) Nitrobenzene (iii) Phenol (iv) Benzaldehyde

48. Picric acid is :

(i) Trinitrotoluene (ii) Trinitroaniline (iii) Trinitrophenol (iv) None of these

49. Sodium phenoxide on heating with ethyl iodide gives :

(i) Phenol (ii) Iodobenzene (iii) Ethyl benzene (iv) Phenetole

50. Which of the following compounds is aspirin?
(i) Salicylic acid *(ii) Methyl salicylate* (iii) Acetyl salicylic acid (iv) Salicylaldehyde

51. Phenol reacts with phthalic anhydride in presence of conc H_2SO_4 to give :
(i) Fluorescein (ii) Aspirin (iii) Phenolphthalein (v) Resorcinol

52. **Fill in the blanks :**

(i) The I.U.P.A.C. name of glycerol is ....

(ii) Alcohols have higher boiling points than isomeric ethers due to ....

(iii) Isopropyl alcohol when passed over heated copper at 300°C gives ....

(iv) An alcohol reacts with Grignard reagent to give an ....

(v) The alcohols containing two —OH groups are called as ....

(vi) The dehydration of glycol with conc. H_2SO_4 gives ....

(vii) *The alkaline hydrolysis of an ester is known as* ....

(viii) Oil of winter green is chemically ....

(ix) Phenols are .... acidic than alcohols.

(x) Picric acid is ....

(xi) Phenol and benzyl alcohol can be distinguished by using .... reagent.

(xii) The benzoylation of phenol in presence of NaOH is known as .... reaction.

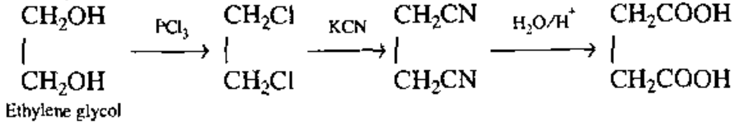
(xiii) The conversion of phenyl allyl ether to *o*-allyl phenols by means of heat is known as ....

ANSWERS

10. The increasing order of acidity is (lowest → highest) : (A) < (C) < (B) < (D)

As the number of alkyl groups attached to the carbon bearing the hydroxyl group increases, the acidity decreases. Alkyl groups are electron-releasing and they tend to stabilise the alcohol, making it more difficult to lose a proton. In addition, the presence of more alkyl groups destabilises the negatively charged conjugate base.

23. Following steps are involved :



$$\begin{array}{c} CH_2OH \\ | \\ CH_2OH \end{array} \xrightarrow{PCl_3} \begin{array}{c} CH_2Cl \\ | \\ CH_2Cl \end{array} \xrightarrow{KCN} \begin{array}{c} CH_2CN \\ | \\ CH_2CN \end{array} \xrightarrow{H_2O/H^+} \begin{array}{c} CH_2COOH \\ | \\ CH_2COOH \end{array}$$

Ethylene glycol

30. Following tests are used :

(i) Reaction with bromine water : When a solution of phenol in water is treated with bromine water, a yellow precipitate of 2, 4, 6 tribromophenol is formed. Ethyl alcohol does not give this test.

(ii) Reaction with $FeCl_3$: Phenol gives purple colour with neutral ferric chloride solution, while ethyl alcohol does not give this test.

31. When phenol is heated with phthalic anhydride and a few drops of concentrated sulphuric acid, phenolphthalein is formed, which gives red colour with an alkali. Benzyl alcohol does not give this test.

39. (iii), **40.** (i), **41.** (ii), **42.** (ii), **43.** (iii), **44.** (i), **45.** (i), **46.** (i), **47.** (iii), **48.** (iii), **49.** (iv),
50. (iii), **51.** (iii), **52.** (i) propane 1, 2, 3-triol (ii) hydrogen bonding
(iii) acetone, (iv) alkane, (v) glycols, (vi) dioxane, (vii) saponification,
(viii) methyl salicylate, (ix) more, (x) 2, 4, 6 trinitrophenol, (xi) 1% $FeCl_2$,
(xii) Schottmann-Baumann (xiii) Claisen rearrangement

UNIT

2

CARBOXYLIC ACIDS

LEARNING OBJECTIVES

- **Carboxylic Acids**
- **Nomenclature and Structure of Carboxylic Acids**
- **General Methods of Preparation and Properties of Carboxylic Acids**
- **Acidity of Carboxylic Acids**
- **Tartaric Acid**
- **Citric Acid**
- **Aromatic Carboxylic Acids**
- **Benzoic Acid**
- **Conversions of Benzoic Acid**
- **Explanation of Facts**
- **Salicylic Acid**
- **Anthranilic Acid**
    - **Summary**
    - **Student Activity**
    - **Test Yourself**

• 2.1. CARBOXYLIC ACIDS

Organic compounds with one or more carboxylic groups are acidic in nature and hence are called *carboxylic acids*. In fact, a carboxylic group is made up of $-\overset{\overset{\displaystyle O}{\|}}{C}-$, carbonyl group and —OH, hydroxyl group. Therefore, the group, $-\overset{\overset{\displaystyle O}{\|}}{C}-OH$ is named as *carboxylic* (carbonyl hydroxyl) group. However, a carboxylic group neither gives the characteristic reactions of carbonyl group nor of alcoholic group.

Carboxylic acids are further termed as *monocarboxylic, dicarboxylic, tricarboxylic acids*, according as the number of COOH groups present in the molecule is 1, 2, 3, or more. The basicity of these carboxylic acids depends upon the number of carboxylic groups present in a molecule. Thus, a monocarboxylic acid is monobasic and a dicarboxylic acid is dibasic in nature and so on.

Carboxylic acids may also be considered as the carboxylic derivatives of hydrocarbons as they may be obtained by the replacement of one or more hydrogen atoms by carboxylic groups, *e.g.*,

$$\underset{\text{Methane}}{CH_4} \longrightarrow \underset{\text{Acetic acid}}{CH_3COOH}$$

These acids may also be considered as the oxidation products of hydrocarbons. in which the end $-CH_3$ group is oxidised to —COOH group, *e.g.*,

$$\underset{\text{Methane}}{H{-}CH_3} \xrightarrow{[O]} \underset{\text{Methyl alcohol}}{H{-}CH_2OH} \xrightarrow{[O]} \underset{\text{Formaldehyde}}{H{-}CHO} \xrightarrow{[O]} \underset{\text{Formic acid}}{H{-}COOH}$$

$$\underset{\text{Ethane}}{CH_3{-}CH_3} \xrightarrow{[O]} \underset{\text{Ethyl alcohol}}{CH_3{-}CH_2OH} \xrightarrow{[O]} \underset{\text{Acetaldehyde}}{CH_3{-}CHO} \xrightarrow{[O]} \underset{\text{Acetic acid}}{CH_3{-}COOH}$$

Monocarboxylic acids are commonly referred to as *fatty acids* since higher members of this homologous series, *e.g.*, palmitic acid, stearic acid, etc., form fats with glycerol. The general formula of this homologous series is represented as $C_nH_{2n+1}COOH$. They may be represented in general by the formula RCOOH, where R may either be a hydrogen atom or any alkyl radical. Since one hydrogen of this carboxylic group may be substituted by a metal, they are considered as monobasic acids. Monocarboxylic acids are also known as **monoprotic acids** as they give one proton when dissolved.

2.2. NOMENCLATURE AND STRUCTURE OF CARBOXYLIC ACIDS

[I] Nomenclature of Carboxylic Acids

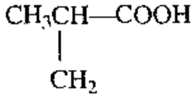
Monocarboxylic acids are named by three main systems.

(i) Trivial or common system : The first four members have derived their names from the Latin or Greek words indicating their source of propagation or presence, *e.g.*, HCOOH was named as formic acid from the Latin word **formica** meaning ants (the first source of origin), CH_3COOH as acetic acid from the Latin word *acetum* meaning vinegar (the first source of presence), C_2H_5COOH as propionic acid from the Greek word proton-pion, (proton = first, pion = fat) and C_3H_7COOH as butyric acid from Latin word *butyrum* meaning butter.

The higher members of this series are named on the basis of the number of carbon atoms present in them, *e.g.*, carboxylic acid containing 6C atoms is named as hexoic acid, containing 7C-atoms as heptoic acid etc.

In this system, acids having a single branch of methyl group in the normal straight carbon chain farthest removed from the carboxylic group are named by adding the suffix *iso*— to the common name of the acids with the same number of carbon atoms, *e.g.*,

$CH_3CH_2CH_2COOH$
Butyric acid

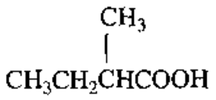


$$\underset{\substack{|\\ CH_2}}{CH_3CH}{-}COOH$$

Isobutyric acid

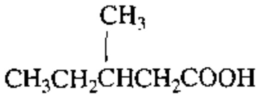
The higher branched-chain members of this series are named as the alkyl substituted derivatives of the normal parent acids. The positions of substituents in the straight chain being indicated by Greek letters, *i.e.*, the carbon attached to —COOH group is designated as α, next to α as β, then γ and so on.

$$[-\overset{\delta}{C}-\overset{\gamma}{C}-\overset{\beta}{C}-\overset{\alpha}{C}-COOH]$$



$$CH_3CH_2\overset{\substack{CH_3\\ |}}{C}HCOOH$$

α-Methyl butyric acid



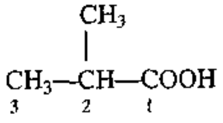
$$CH_3CH_2\overset{\substack{CH_3\\ |}}{C}HCH_2COOH$$

β-Methyl butyric acid

(ii) As derivatives of acetic acid : In this system, members of this homologous series, except formic acid (HCOOH), are named as alkyl derivatives of acetic acid, *e.g.*,

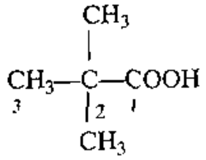
$$\underset{\text{Methyl acetic acid}}{CH_3CH_2COOH} \qquad \underset{\text{Dimethyl acetic acid}}{(CH_3)_2CHCOOH} \qquad \underset{\text{Trimethyl acetic acid}}{(CH_3)_3C.COOH}$$

(iii) IUPAC system : According to this system, members are named by replacing '*c*' from the name of the parent hydrocarbon by suffix **'oic'** and using the word **acid**, *e.g.*, HCOOH is named as methanoic acid (from methane, CH_4), CH_3COOH as ethanoic acid (from ethane, C_2H_6), etc. The positions of substituents in the main chain is indicated by numbering the carbon atoms of the main chain, giving the number 1 to the carbon of the —COOH group, *e.g.*,



$$\underset{3}{CH_3}{-}\underset{2}{\overset{\substack{CH_3\\ |}}{CH}}{-}\underset{1}{COOH}$$

2-Methyl propanoic acid



$$\underset{3}{CH_3}{-}\underset{\substack{|\,2\\ CH_3}}{\overset{\substack{CH_3\\ |}}{C}}{-}\underset{1}{COOH}$$

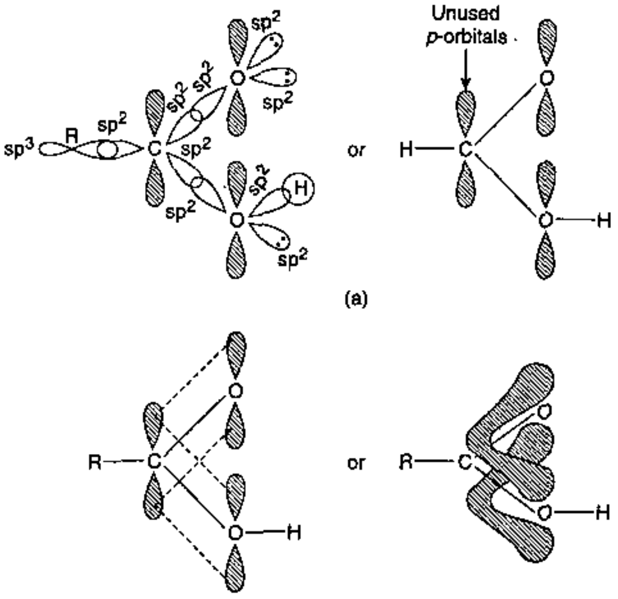
2, 2-Dimethyl propanoic acid

A few members of this homologous series with their names by all the three systems are listed in the table given below :

Formula	Trivial name	As derivative of acetic acid	IUPAC name
$H.COOH$	Formic acid	—	Methanoic acid
CH_3COOH	Acetic acid	—	Ethanoic acid
CH_3CH_2COOH	Propionic acid	Methyl acetic acid	Propanoic acid
$CH_3CH_2CH_2COOH$	Butyric acid	Ethyl acetic acid	Butanoic acid
$CH_3\underset{\underset{CH_3}{\vert}}{C}HCOOH$	Isobutyric acid	Dimethyl acetic acid	2-Methyl propanoic acid
$CH_3CH_2CH_2CH_2COOH$	Valeric acid	*n*-Propyl acetic acid	Pentanoic acid
$CH_3\underset{\underset{CH_3}{\vert}}{CH}.CH_2COOH$	Isovaleric acid (β-Methyl butyric acid)	Isopropyl acetic acid	3-Methyl butanoic acid
$CH_3CH_2—\underset{\underset{CH_3}{\vert}}{C}HCOOH$	Active valeric acid (α-Methyl butyric acid)	Ethyl methyl acetic acid	2-Methyl butanoic acid

[II] Structure of Carboxylic Acids

In a carboxylic group, atoms are arranged in a planar form as shown by electron and neutron diffraction studies. Therefore, the carboxylic carbon and the two oxygen atoms in —COOH group are sp^2 hybridised. The three sp^2 hybridised orbitals of the carbon of the carboxylic group overlap with two sp^2 orbitals of the two oxygen atoms and one sp^2 hybridised orbital of the alkyl group to form three σ bonds. The sp^2 hybridised orbital of one of the two oxygen atoms further overlaps with *s*-orbital of a hydrogen atom to form a σ bond. Each of the two oxygen atoms and the carboxylic carbon are now left with one *p* orbital perpendicular to the σ bonding skeleton. All these three unused orbitals overlap and the resulting π bond is partly delocalized between carbon and one oxygen and the carbon and the second oxygen. It is shown in fig. 1. Due to this delocalization, it can be explained as to why (a) the C—O single bond of carboxylic group is shorter (1·36Å) than the normal C—O single bond (1·43Å) in alcohols and ethers? and (b) the C—O double bond in carboxylic group is slightly longer (1·23Å) than the normal C═O double bond (1·20Å) in ketones and aldehydes?



(a)

(b)

Fig. 1. (a) σ-Skeleton of the carboxylic acid molecule. (b) Delocalized π-electron cloud.

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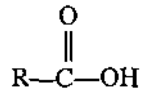
The structure of carboxylic acids can be represented as

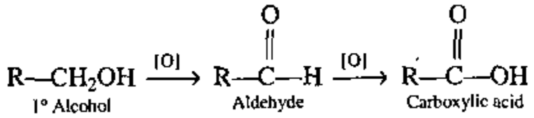


$$R-\overset{O}{\overset{\|}{C}}-OH$$

2.3. GENERAL METHODS OF PREPARATION AND PROPERTIES OF CARBOXYLIC ACIDS

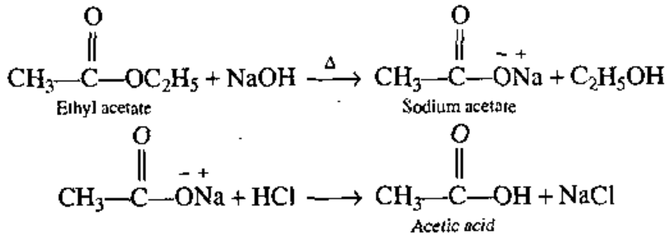
[I] General Methods of Preparation

(1) Oxidation of primary alcohols or aldehydes : With a mixture of $K_2Cr_2O_7$ and H_2SO_4, primary alcohols or aldehydes form carboxylic acids.



$$\underset{1^\circ\text{ Alcohol}}{R-CH_2OH} \xrightarrow{[O]} \underset{\text{Aldehyde}}{R-\overset{O}{\overset{\|}{C}}-H} \xrightarrow{[O]} \underset{\text{Carboxylic acid}}{R-\overset{O}{\overset{\|}{C}}-OH}$$

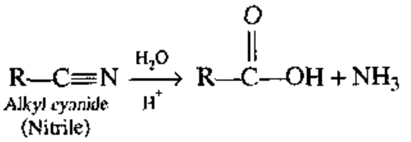
(2) Hydrolysis of ester : On boiling an ester with concentrated aqueous NaOH, sodium salt of the acid is formed. This on treatment with dil. HCl, gives the corresponding acid.



$$\underset{\text{Ethyl acetate}}{CH_3-\overset{O}{\overset{\|}{C}}-OC_2H_5} + NaOH \xrightarrow{\Delta} \underset{\text{Sodium acetate}}{CH_3-\overset{O}{\overset{\|}{C}}-\overset{-}{O}\overset{+}{Na}} + C_2H_5OH$$

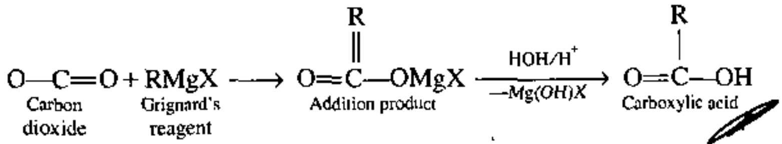
$$CH_3-\overset{O}{\overset{\|}{C}}-\overset{-}{O}\overset{+}{Na} + HCl \longrightarrow \underset{\text{Acetic acid}}{CH_3-\overset{O}{\overset{\|}{C}}-OH} + NaCl$$

(3) Hydrolysis of nitriles or alkyl cyanides : The nitriles or alkyl cyanides on hydrolysis form carboxylic acids.



$$\underset{\substack{\text{Alkyl cyanide}\\\text{(Nitrile)}}}{R-C\equiv N} \xrightarrow[H^+]{H_2O} R-\overset{O}{\overset{\|}{C}}-OH + NH_3$$

(4) Reaction of Grignard's reagent with CO_2 : Grignard's reagent (RMgX) reacts with CO_2 to form an addition product which on hydrolysis gives an acid.



$$\underset{\substack{\text{Carbon}\\\text{dioxide}}}{O-C=O} + \underset{\substack{\text{Grignard's}\\\text{reagent}}}{RMgX} \longrightarrow \underset{\text{Addition product}}{O=\overset{R}{\overset{\|}{C}}-OMgX} \xrightarrow[-Mg(OH)X]{HOH/H^+} \underset{\text{Carboxylic acid}}{O=\overset{R}{\overset{|}{C}}-OH}$$

(5) From reactive methylene compounds : Compounds in which a methylene group ($-CH_2-$) is flanked by two electronegative groups (*e.g.*, $-\overset{O}{\overset{\|}{C}}-$, $-\overset{O}{\overset{\|}{C}}-OR$, $-C\equiv N$, etc.) are called reactive methylene compounds. The hydrogen atoms of such reactive methylene group may easily be replaced by a metal like sodium which in turn may be replaced by an alkyl radical. These reactive methylene compounds and their alkyl derivatives on hydrolysis produce monocarboxylic acids, *e.g.*,

$$\underset{\text{Acetoacetic ester}}{\overset{OH}{CH_3CO}\,\vdots\,\overset{H}{}CH_2COO\overset{H}{}\,\vdots\,\overset{OH}{C_2H_5}} \xrightarrow[\text{Alcoholic}]{\text{Conc. KOH}} \underset{\text{Acetic acid (2 moles)}}{CH_3COOH + CH_3COOH} + C_2H_5OH$$

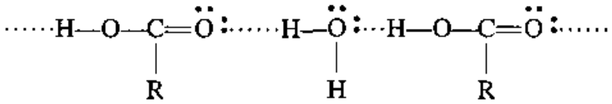
$$\underset{\text{Monoalkyl derivative}}{CH_3COCHRCOOC_2H_5} + 2H_2O \xrightarrow[\text{Alcoholic}]{\text{Conc. KOH}} CH_3COOH + \underset{\text{Carboxylic acid}}{RCH_2COOH} + C_2H_5OH$$

$$\underset{\text{Malonic ester}}{CH_2(COOC_2H_5)_2} + 2H_2O \xrightarrow[\text{(ii) HCl}]{\text{(i) KOH}} \underset{\text{Malonic acid}}{CH_2(COOH)_2} \xrightarrow[-CO_2]{\Delta} \underset{\text{Acetic acid}}{CH_3COOH}$$

$$\underset{\substack{\text{Monoalkyl derivative}\\\text{of malonic ester}}}{RCH\,(COOC_2H_5)_2} + 2H_2O \xrightarrow[\text{(ii) HCl}]{\text{(i) KOH}} \underset{\substack{\text{Monoalkyl}\\\text{malonic acid}}}{RCH\,(COOH)_2} \xrightarrow[-CO_2]{\Delta} \underset{\text{Carboxylic acid}}{RCH_2COOH}$$

[II] General Physical Properties

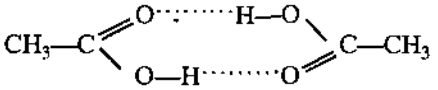
The first nine members of the series are colourless liquids, higher ones are colourless wax like solids. The first three members (C_1—C_3) possess pungent odour, butyric acid (C_4) has rancid-butter odour, while the higher ones have goat-like odour. Lower members upto C_4 are completely soluble in water due to the formation of H-bonds between the hydrogen of acid and oxygen of water and oxygen of acid and hydrogen of water.



$$\cdots\cdots \underset{\textstyle R}{\text{H—O—}\underset{|}{\text{C}}\text{=}\ddot{\text{O}}}:\cdots\cdots \text{H—}\underset{\underset{\textstyle H}{|}}{\ddot{\text{O}}}:\cdots \text{H—O—}\underset{\underset{\textstyle R}{|}}{\text{C}}\text{=}\ddot{\text{O}}:\cdots\cdots$$

Valeric acid (C_5) is slightly soluble, while members from C_6 onwards are insoluble in water.

All the monocarboxylic acids are soluble in organic solvents like alcohol, carbon tetrachloride and benzene. In benzene, the lower acids like formic and acetic acid, occur in dimeric state due to hydrogen bonding.



Dimer state of acetic acid

The boiling points of fatty acids are abnormally high, even higher than corresponding alcohols with same value of molecular weight, *e.g.*, the boiling point of HCOOH (mol. wt. 46) is 100°C, while that of C_2H_5OH (mol. wt. 46) is only 78°C. The abnormally high boiling points of fatty acids indicate the greater strength of hydrogen bonds in fatty acids than in alcohols. The boiling and melting points of fatty acids show a regular gradation with the increase in molecular weight.

[III] General Chemical Properties

The properties of carboxylic acids can be divided into four types :

(a) Reactions involving removal of a proton from O—H group by a base.

(b) Reactions at the carbonyl carbon (> CO) involving attack of a nucleophile.

(c) Reactions involving attack of the carboxylic group.

(d) Reactions involving attack of a halogen on an α-carbon.

(1) Reactions Involving Removal of Proton from Hydroxyl Group of Carboxylic Group

(i) Action of metals : Metals like Na, Ca, K, Zn etc. react with carboxylic acids to form salts and form hydrogen.

$$\underset{\substack{\text{Carboxylic}\\\text{acid}}}{2R\,.\,COOH} + 2Na \longrightarrow \underset{\text{Sodium carboxylate}}{2RCOONa} + H_2$$

(ii) Action of bases : Being acidic in nature, fatty acids react with both strong (*e.g.*, NaOH, KOH etc.) and mild (*e.g.*, Na_2CO_3, $NaHCO_3$ etc.) alkalies to form corresponding salts.

$$RCOOH + \underset{\text{Sodium hydroxide}}{NaOH} \longrightarrow RCOONa + H_2O$$

$$2RCOOH + \underset{\text{Sodium carbonate}}{Na_2CO_3} \longrightarrow 2RCOONa + H_2O + CO_2\uparrow$$

$$RCOOH + \underset{\text{Sodium bicarbonate}}{NaHCO_3} \longrightarrow RCOONa + H_2O + CO_2\uparrow$$

The latter two reactions, (particularly with sodium bicarbonate) liberate carbon dioxide, hence are used as tests for carboxylic acids.

Sodium or potassium salts of the long-chain fatty acids are the contents of soaps, *e.g.*,

$$\underset{\text{Sodium palmitate}}{C_{15}H_{31}COONa} \qquad \underset{\text{Sodium stearate}}{C_{17}H_{35}COONa}$$

(iii) Action of organic bases : Organic bases also react with fatty acids forming salts, *e.g.*, amines of all types, *i.e.*, primary, secondary and tertiary, react with these acids to form salts, *e.g.*,

$$RCOOH + \underset{\text{Primary amine}}{RNH_2} \longrightarrow \underset{\text{Substituted amide}}{RCONHR} + H_2O$$

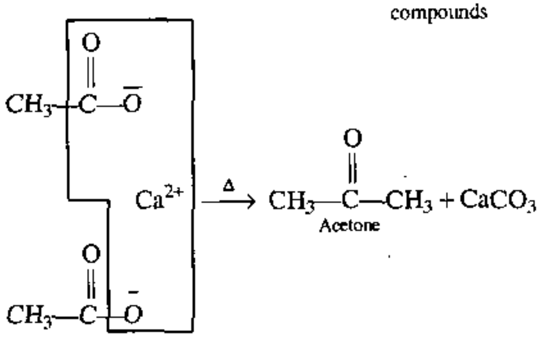
(iv) Reactions of salts of fatty acids

(a) ***Action of heat on sodium salts.*** Anhydrous sodium salts of fatty acids on heating with soda lime (NaOH + CaO) give alkanes with one carbon atom less.

$$\underset{\text{Sodium salt}}{RCOONa} + \underset{\text{Soda lime}}{NaOH\,(CaO)} \longrightarrow \underset{\text{Alkane}}{RH} + Na_2CO_3$$

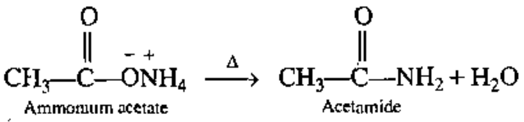
(b) ***Action of heat on calcium or barium salts.*** Anhydrous calcium or barium salts of fatty acids when heated dry, give ketones.

$$\underset{\text{Calcium salt}}{(RCOO)_2Ca} \xrightarrow{\text{Dry heating}} \underset{\text{Carbonyl compounds}}{RCOR} + CaCO_3$$



(c) ***Action of heat on ammonium salts.*** Ammonium salts of fatty acids on heating alone form amides with the liberation of one molecule of water.

$$\underset{\text{Amm. salt}}{RCOONH_4} \xrightarrow{\Delta} \underset{\text{Amide}}{RCONH_2} + H_2O$$

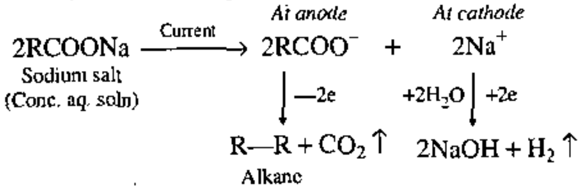


$$\underset{\text{Ammonium acetate}}{CH_3-\overset{O}{\overset{\|}{C}}-\overset{-\ +}{ONH_4}} \xrightarrow{\Delta} \underset{\text{Acetamide}}{CH_3-\overset{O}{\overset{\|}{C}}-NH_2} + H_2O$$

However, when heated with some dehydrating agent, *e.g.*, P_2O_5 *etc.*, *they liberate two* molecules of water producing cyanides or nitriles.

$$RCOONH_4 \xrightarrow[\Delta]{P_2O_5} \underset{\text{Alkyl cyanide}}{RCN} + 2H_2O$$

(d) Electrolysis of sodium or potassium salts. When concentrated aqueous solution of sodium or potassium salts of fatty acids are subjected to electrolysis they produce alkanes.

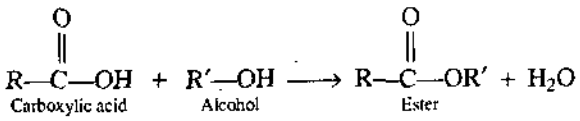


$$\begin{tikzcd}[column sep=small] & \text{At anode} & & \text{At cathode} \\ \underset{\text{(Conc. aq. soln)}}{\underset{\text{Sodium salt}}{2RCOONa}} \arrow[r, "\text{Current}"] & 2RCOO^- \arrow[d, "-2e"] & + & 2Na^+ \arrow[d, "+2e", "+2H_2O"'] \\ & \underset{\text{Alkane}}{R-R} + CO_2\uparrow & & 2NaOH + H_2\uparrow \end{tikzcd}$$

(2) Reactions at the Carbonyl Carbon Involving Attack by a Nucleophile

These are the reactions in which a nucleophile attacks on the carbonyl carbon of the carboxylic ($-\overset{O}{\overset{\|}{C}}-OH$) group forming derivatives of fatty acids.

(i) Esterification : The reaction between an alcohol and a fatty acid (or any other acid) with the liberation of water molecule is known as *esterification* and the product formed is known as an *ester.* The reaction is catalysed by a mineral acid (*e.g.*, HCl, H_2SO_4 etc.) and is reversible.

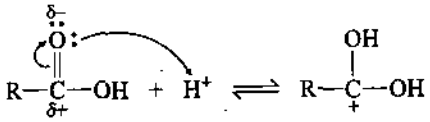


$$\underset{\text{Carboxylic acid}}{R-\overset{O}{\overset{\|}{C}}-OH} + \underset{\text{Alcohol}}{R'-OH} \longrightarrow \underset{\text{Ester}}{R-\overset{O}{\overset{\|}{C}}-OR'} + H_2O$$

$$\underset{\text{Acetic acid}}{CH_3COOH} + \underset{\text{Ethyl alcohol}}{HOC_2H_5} \xrightarrow{\text{Conc. } H_2SO_4} \underset{\text{Ethyl acetate}}{CH_3COOC_2H_5} + H_2O$$

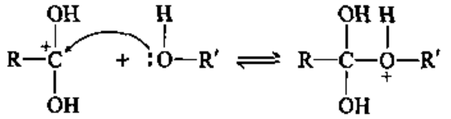
Mechanism : According to Ingold, the acyl-oxygen fission is involved in acid catalysed esterification.

Step 1. Protonation of carboxylic acid.



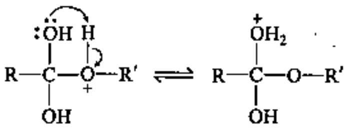
$$R-\underset{\delta+}{\overset{\overset{\delta-}{\ddot{O}:}}{\overset{\|}{C}}}-OH + H^+ \rightleftharpoons R-\underset{+}{\overset{OH}{\overset{|}{C}}}-OH$$

Step 2. Attack of protonated form by nucleophile R′OH.



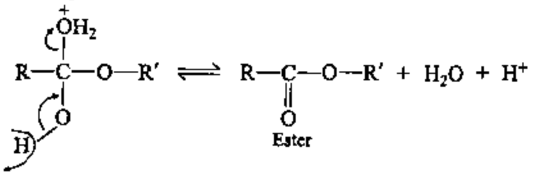
$$R{-}\overset{\overset{OH}{|}}{\underset{\underset{OH}{|}}{\overset{+}{C}}} + :\overset{\overset{H}{|}}{O}{-}R' \rightleftharpoons R{-}\overset{\overset{OH}{|}}{\underset{\underset{OH}{|}}{C}}{-}\overset{\overset{H}{|}}{\underset{+}{O}}{-}R'$$

Step 3. Hydrogen ion transfer



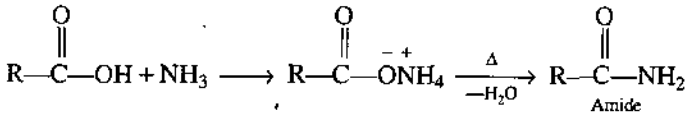
$$R{-}\overset{\overset{:\ddot{O}H}{|}}{\underset{\underset{OH}{|}}{C}}{-}\overset{\overset{H}{|}}{\underset{+}{O}}{-}R' \rightleftharpoons R{-}\overset{\overset{\overset{+}{O}H_2}{|}}{\underset{\underset{OH}{|}}{C}}{-}O{-}R'$$

Step 4. Elimination of proton and a water molecule.

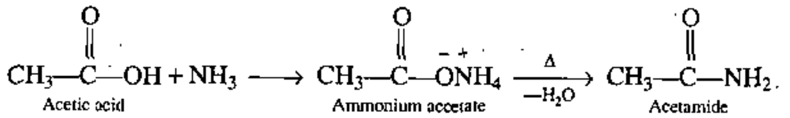


$$R{-}\overset{\overset{\overset{+}{O}H_2}{|}}{\underset{\underset{O{-}H}{|}}{C}}{-}O{-}R' \rightleftharpoons \underset{\text{Ester}}{R{-}\underset{\underset{O}{\|}}{C}{-}O{-}R'} + H_2O + H^+$$

(ii) Formation of amides : Carboxylic acids react with ammonia to form salts, which on heating give amides.

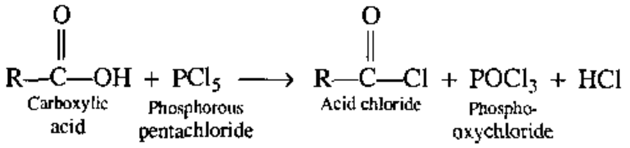


$$R{-}\overset{\overset{O}{\|}}{C}{-}OH + NH_3 \longrightarrow R{-}\overset{\overset{O}{\|}}{C}{-}\overset{-}{O}\overset{+}{N}H_4 \xrightarrow[-H_2O]{\Delta} \underset{\text{Amide}}{R{-}\overset{\overset{O}{\|}}{C}{-}NH_2}$$

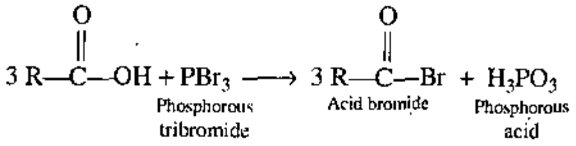


$$\underset{\text{Acetic acid}}{CH_3{-}\overset{\overset{O}{\|}}{C}{-}OH} + NH_3 \longrightarrow \underset{\text{Ammonium acetate}}{CH_3{-}\overset{\overset{O}{\|}}{C}{-}\overset{-}{O}\overset{+}{N}H_4} \xrightarrow[-H_2O]{\Delta} \underset{\text{Acetamide}}{CH_3{-}\overset{\overset{O}{\|}}{C}{-}NH_2}.$$

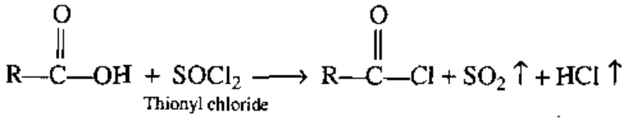
(iii) Formation of acid halides : When fatty acids react with reagents like phosphorous halides (*e.g.*, PCl_5, PCl_3, PBr_3, etc.) or thionyl halides (*e.g.*, $SOCl_2$, $SOBr_2$), their —OH group is replaced by halogen atom forming corresponding acid halides.



$$\underset{\text{Carboxylic acid}}{R{-}\overset{\overset{O}{\|}}{C}{-}OH} + \underset{\text{Phosphorous pentachloride}}{PCl_5} \longrightarrow \underset{\text{Acid chloride}}{R{-}\overset{\overset{O}{\|}}{C}{-}Cl} + \underset{\text{Phospho-oxychloride}}{POCl_3} + HCl$$



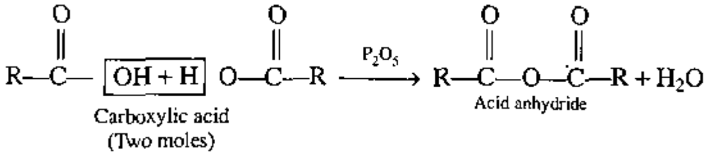
$$3\,R{-}\overset{\overset{O}{\|}}{C}{-}OH + \underset{\text{Phosphorous tribromide}}{PBr_3} \longrightarrow 3\,\underset{\text{Acid bromide}}{R{-}\overset{\overset{O}{\|}}{C}{-}Br} + \underset{\text{Phosphorous acid}}{H_3PO_3}$$



$$R{-}\overset{\overset{O}{\|}}{C}{-}OH + \underset{\text{Thionyl chloride}}{SOCl_2} \longrightarrow R{-}\overset{\overset{O}{\|}}{C}{-}Cl + SO_2\uparrow + HCl\uparrow$$

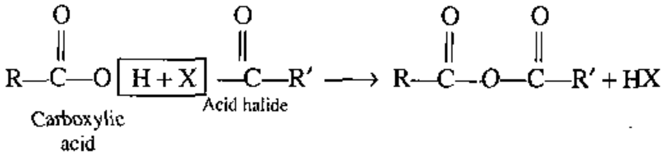
The best method of preparing acid halides from acids is the use of thionyl halides since the by-products, *i.e.*, HX, SO_2, formed are gaseous and escape, leaving pure acid halides.

(iv) Formation of acid anhydrides : Fatty acids undergo intermolecular dehydration in presence of dehydrating agents such as phosphorous pentaoxide etc., to give corresponding acid anhydrides.



$$\underset{\text{Carboxylic acid (Two moles)}}{R{-}\overset{\overset{O}{\|}}{C}{-}\boxed{OH + H}\,O{-}\overset{\overset{O}{\|}}{C}{-}R} \xrightarrow{P_2O_5} \underset{\text{Acid anhydride}}{R{-}\overset{\overset{O}{\|}}{C}{-}O{-}\overset{\overset{O}{\|}}{C}{-}R} + H_2O$$

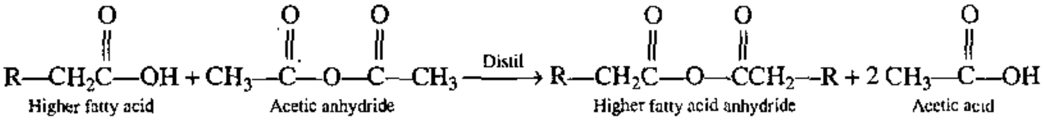
Acid anhydrides are also formed by the action of an acid halide on fatty acids.



$$\underset{\text{Carboxylic acid}}{R{-}\overset{\overset{O}{\|}}{C}{-}O}\boxed{H + X}\underset{\text{Acid halide}}{{-}\overset{\overset{O}{\|}}{C}{-}R'} \longrightarrow R{-}\overset{\overset{O}{\|}}{C}{-}O{-}\overset{\overset{O}{\|}}{C}{-}R' + HX$$

The method has a special use in the preparation of mixed acid anhydrides. However, use of sodium salts of fatty acids are preferred over free acid molecules in the above method.

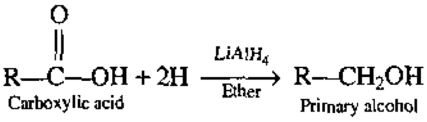
Simple anhydrides of higher fatty acids are also prepared by distilling them with acetic anhydride.



$$\underset{\text{Higher fatty acid}}{R-CH_2\overset{\overset{O}{\|}}{C}-OH} + \underset{\text{Acetic anhydride}}{CH_3-\overset{\overset{O}{\|}}{C}-O-\overset{\overset{O}{\|}}{C}-CH_3} \xrightarrow{\text{Distil}} \underset{\text{Higher fatty acid anhydride}}{R-CH_2\overset{\overset{O}{\|}}{C}-O-\overset{\overset{O}{\|}}{C}CH_2-R} + 2\,\underset{\text{Acetic acid}}{CH_3-\overset{\overset{O}{\|}}{C}-OH}$$

Though the reaction is reversible yet the equilibrium remains on the right hand side since the *acetic acid formed is of comparatively low boiling point and hence distils over during the reaction.*

(v) Reduction : Fatty acids are difficult to be reduced by conventional reducing agents such as Na/C_2H_5OH, $H_2/$ catalyst, etc. However, strong reducing agents, *e.g.*, lithium aluminium hydride ($LiAlH_4$) reduces them smoothly to primary alcohols.



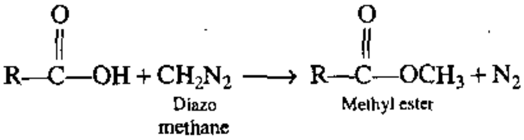
$$\underset{\text{Carboxylic acid}}{R-\overset{\overset{O}{\|}}{C}-OH} + 2H \xrightarrow[\text{Ether}]{LiAlH_4} \underset{\text{Primary alcohol}}{R-CH_2OH}$$

An advantage of the use of $LiAlH_4$ *is that it does not* attack on unsaturation. Hence, unsaturated acid is directly reduced to an unsaturated primary alcohol.

$$\underset{\text{Unsaturated acid}}{RCH{=}CHCOOH} + 2H \xrightarrow[\text{Ether}]{LiAlH_4} \underset{\text{Unsaturated alcohol}}{RCH{=}CHCH_2OH}$$

(3) Reactions Involving Attack of Carboxylate Ion

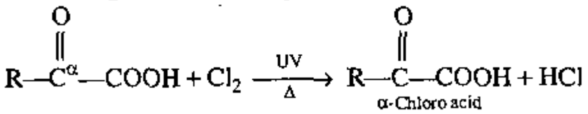
Monocarboxylic acids react with diazomethane to form the corresponding methyl ester.



$$R-\overset{\overset{O}{\|}}{C}-OH + \underset{\text{Diazo methane}}{CH_2N_2} \longrightarrow \underset{\text{Methyl ester}}{R-\overset{\overset{O}{\|}}{C}-OCH_3} + N_2$$

(4) Reactions Involving Attack of a Halogen Atom on α-Carbon

(i) Halogenation : *Fatty acids are attacked by halogens such as chlorine and bromine in* presence of ultraviolet light to form halogen substituted acids.



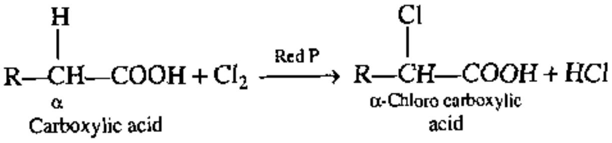
$$R-\overset{\overset{O}{\|}}{C^{\alpha}}-COOH + Cl_2 \xrightarrow[\Delta]{UV} \underset{\alpha\text{-Chloro acid}}{R-\overset{\overset{O}{\|}}{C}-COOH} + HCl$$

The α-hydrogen atoms of the fatty acids are all replaced one by one depending upon the conditions of reaction, *e.g.*, when chlorine is passed into hot acetic acid in presence of ultraviolet *light, all the three mono, di and trichloroacetic acids are obtained.*

$$\underset{\text{Acetic acid}}{CH_3-COOH} \xrightarrow[UV/\Delta]{Cl_2} \underset{\text{Monochloroacetic acid}}{CH_2Cl-COOH} \xrightarrow[UV/\Delta]{Cl_2} \underset{\text{Dichloroacetic acid}}{CHCl_2-COOH} \xrightarrow[UV/\Delta]{Cl_2} \underset{\text{Trichloroacetic acid}}{CCl_3-COOH}$$

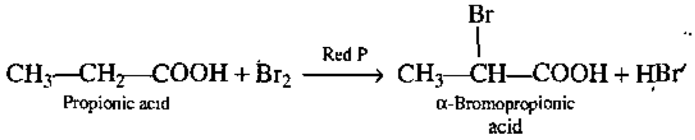
Higher fatty acids are attacked by halogens randomly along the hydrocarbon chain producing all types, *i.e.*, α, β, γ etc., halogen substituted acids.

(ii) Hell-Volhard-Zelinsky, (HVZ) reaction : When a carboxylic acid that contains α-hydrogen is treated with Cl_2 or Br_2 in the presence of phosphorus, the α-hydrogen atoms are replaced by chlorine or bromine atoms. This reaction is known as the Hell-Volhard-Zelinsky (HVZ) *reaction. It is a very good method for preparing* α*-halosubstituted fatty acids.*



$$\underset{\text{Carboxylic acid}}{R-\underset{\alpha}{\overset{\overset{H}{|}}{CH}}-COOH} + Cl_2 \xrightarrow{\text{Red P}} \underset{\alpha\text{-Chloro carboxylic acid}}{R-\overset{\overset{Cl}{|}}{CH}-COOH} + HCl$$

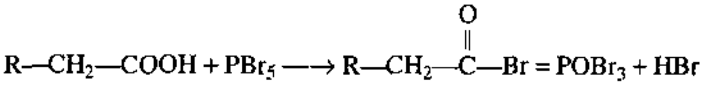
$$CH_3COOH + Cl_2 \xrightarrow{\text{Red P}} \underset{\text{Chloroacetic acid}}{ClCH_2COOH} + HCl$$



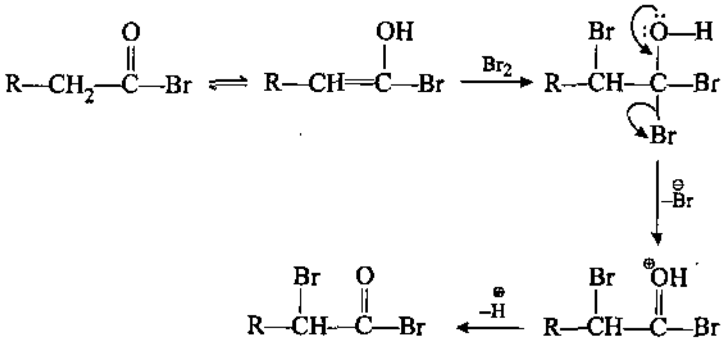
$$\underset{\text{Propionic acid}}{CH_3-CH_2-COOH} + Br_2 \xrightarrow{\text{Red P}} \underset{\alpha\text{-Bromopropionic acid}}{CH_3-\overset{\overset{\large Br}{|}}{CH}-COOH} + HBr$$

Mechanism : In this reaction, first of all phosphorous reacts with halogen to form phosphorus pentahalide which in turn changes the acid into the corresponding acyl halide. The acyl halide having a little enol content undergoes halogenation at α-position via enolic form giving rise to α-halogenated acid halide.

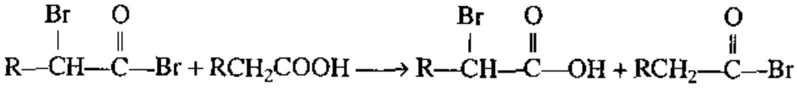
$$2P + 5Br_2 \longrightarrow 2PBr_5$$



$$R-CH_2-COOH + PBr_5 \longrightarrow R-CH_2-\overset{\overset{\large O}{\|}}{C}-Br = POBr_3 + HBr$$



The α-bromoacyl bromide reacts with acid to give α-bromo acid by an interchange reaction.

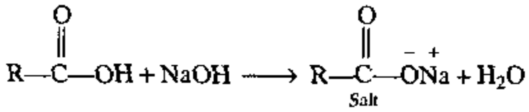


$$R-\overset{\overset{\large Br}{|}}{CH}-\overset{\overset{\large O}{\|}}{C}-Br + RCH_2COOH \longrightarrow R-\overset{\overset{\large Br}{|}}{CH}-\overset{\overset{\large O}{\|}}{C}-OH + RCH_2-\overset{\overset{\large O}{\|}}{C}-Br$$

• 2.4. ACIDITY OF CARBOXYLIC ACIDS

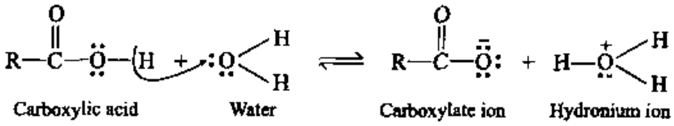
[I] Acidity of Carboxylic Acids

Carboxylic acids are acidic in nature, as they can donate a proton and form salts with bases.

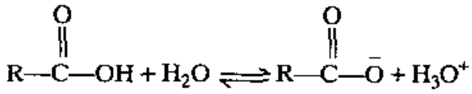


$$R-\overset{\overset{\large O}{\|}}{C}-OH + NaOH \longrightarrow \underset{\text{Salt}}{R-\overset{\overset{\large O}{\|}}{C}-\overset{-}{O}\overset{+}{Na}} + H_2O$$

In an aqueous solution molecules of carboxylic acids interact with water molecules to form carboxylate ions and hydronium ions.



Carboxylic acids are weak acids and the extent of ionisation is described by an equilibrium constant K_a, known as **acidity constant.**

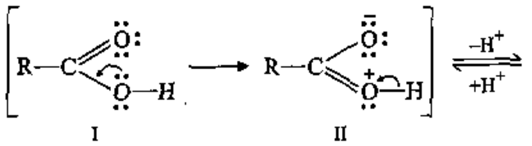


$$R-\overset{\overset{\large O}{\|}}{C}-OH + H_2O \rightleftharpoons R-\overset{\overset{\large O}{\|}}{C}-\overset{-}{O} + H_3O^+$$

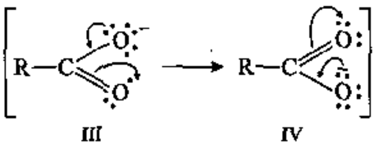
$$K_a = \frac{[RCOO^-][H_3O^+]}{[RCOOH]}$$

The acidity constant describes the relative strength of a weak acid. Higher the value of K_a, stronger will be the acid.

Reason of acidity : The reason for the acidity of carboxylic acids is that they lose a proton readily because the carboxylate ion formed by ionisation or reaction with a base is stabilised by resonance. In the case of a carboxylic acid, both the acid and the carboxylate ion formed by dissociation can exist in two canonical forms.



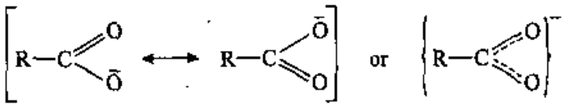
Non-equivalent
(More internal energy; less stable)



Equivalent
(Less internal energy; more stable)

In canonical form II there is separation of opposite charges and some energy must be supplied to do so. Therefore, it would contain more energy and is thus less stable than I. However, the canonical forms III and IV of carboxylate ion have *equivalent structures which are necessarily* of equal stability. Thus, both acid and carboxylate are resonance stabilised but stabilisation is far greater for the carboxylate ion than for the acid.

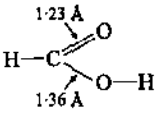
Stability of carboxylate ion : According to the resonance theory, a carboxylate ion is a hybrid of two canonical forms as mentioned above. These forms are of equal stability and contribute equally and in the hybrid ion the carbon is joined to each oxygen by *equivalent "one-and-one-half"* bond. In other words, the negative charge of the carboxylate ion is evenly distributed over both oxygen atoms.



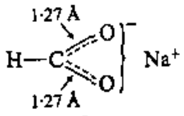
Canonical forms of carboxylate ion

Resonance hybrid

Physical methods have proved that carboxylate ion exists as a resonance hybrid. X-ray and electron diffraction studies have shown that the two carbon-oxygen bond lengths in formic acid are different, while in sodium formate they are equal.



Formic acid

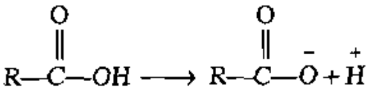


Sodium formate

Further, the bond lengths in the formate ion lie intermediate between those of double bond and single C—O bond.

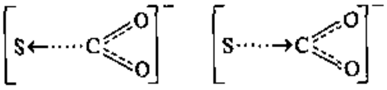
[II] Influence of Substituents on Acidity

We have seen that the acidity of carboxylic acids is due to their ability to release protons.



$$R-\overset{\overset{\displaystyle O}{\|}}{C}-OH \longrightarrow \underset{\text{Carboxylate ion}}{R-\overset{\overset{\displaystyle O}{\|}}{C}-\overset{-}{O}} + \overset{+}{H}$$

The force behind this dissociation is the gain in stability in going from carboxylic acid to carboxylate ion. Thus, any factor that stabilises the carboxylate ion more would facilitate the release of protons and increases the acidity. Conversely, any factor that destabilises the carboxylate ion *would decrease the acidity.* Thus, *electron* withdrawing substituents, *e.g.*, Cl, NO_2, CN, etc., in a carboxylic acid would disperse the negative charge of the COO^-, stabilise it and thus increase the acid strength. On the other hand, the presence of an electron donating substituent such as alkyl group, would intensify the negative charge on the COO^- ion and thus destabilise it, making the carboxylic acid less acidic.

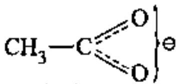


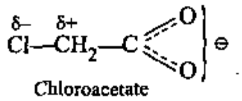
[III] Relative Acidity of Carboxylic Acids

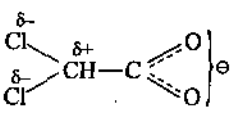
The most important factor affecting the acidity is the *inductive effect* of substituents on the α-carbon atom.

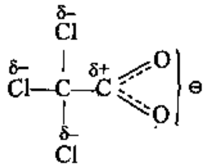
(1) Electron withdrawing substituents like Cl, Br, F, OH, CN increase the acidity.

The most important factor responsible for the acidity of aliphatic acids is the inductive effect of the groups close to the carboxyl group. The inductive effect relays charge through single bonds by displacing bonding electrons towards the electronegative atoms or away from the electropositive atoms. So, electron withdrawing groups increase acidity, while electron releasing groups reduce the acidity. Consider the carboxylate ions formed when acetic acid and its chloro derivatives ionise.


Acetate


Chloroacetate


Dichlorocetate


Trichloroacetate

We know that chlorine is more electronegative than carbon, then C—Cl bond is polarised with the chlorine atom partially negative and the carbon atom partially positive. Therefore, electrons are pulled away from the carboxylate end of the ion towards the chlorine atom. The effect tends to spread the negative charge over more atoms than in acetate ion itself and thus stabilises the ion. The more the chlorine atoms, the greater the effect and greater the strength of the acid. **So, trichloroacetic acid is a stronger acid than acetic acid.**

The strength of the electron withdrawing substituents determines the magnitude of its effect on acidity. For example, fluoroacetic acid is stronger than chloroacetic acid, as F is more electronegative than Cl.

(2) Electron releasing alkyl groups decrease the acidity.

The above fact is because the electron releasing groups increase the negative charge on the carboxylate ion and destabilise it. The loss of protons becomes more difficult. The increase in the size of the alkyl group decreases the acidity of the acids, *e.g.*,

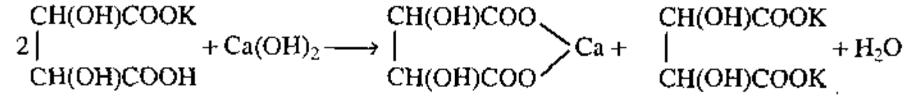
$$\underset{\substack{\text{Formic acid}\\(K_1)}}{HCOOH} \quad \underset{\substack{\text{Acetic acid}\\(K_2)}}{\overset{\alpha}{CH_3}\text{—}COOH} \quad \underset{\substack{\text{Propionic acid}\\(K_3)}}{CH_3\overset{\alpha}{CH_2}COOH}$$

We have $K_1 > K_2 > K_3$.

2.5. TARTARIC ACID

[I] Preparation

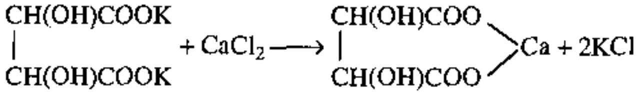
(1) From argol : Argol is obtained as a reddish brown crystalline mass during alcoholic fermentation of grape juice. It is impure potassium hydrogen tartarate. It (crude argol) is dissolved in boiling water and crystallised to obtain pure white substance known as ***cream of tartar*** (potassium hydrogen tartarate). It is dissolved in boiling water and neutralised with $Ca(OH)_2$ when half of the original tartarate separates as insoluble calcium tartarate and the other half remains dissolved as potassium tartarate.



$$2\begin{array}{l}\text{CH(OH)COOK}\\ |\\ \text{CH(OH)COOH}\end{array} + Ca(OH)_2 \longrightarrow \begin{array}{l}\text{CH(OH)COO}\\ |\\ \text{CH(OH)COO}\end{array}\!\Big\rangle Ca + \begin{array}{l}\text{CH(OH)COOK}\\ |\\ \text{CH(OH)COOK}\end{array} + H_2O$$

Potassium hydrogen tartarate (Cream of tartar) — Calcium tartarate (Ppt.) — Potassium tartarate

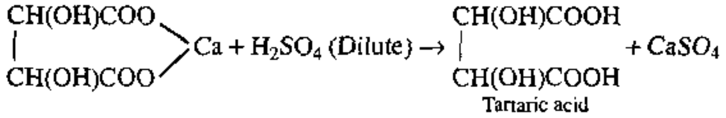
The precipitated calcium tartarate is separated by filteration and $CaCl_2$ is added to the filterate, when the soluble potassium tartarate is precipitated again as calcium tartarate.



$$\begin{array}{l}\text{CH(OH)COOK}\\ |\\ \text{CH(OH)COOK}\end{array} + CaCl_2 \longrightarrow \begin{array}{l}\text{CH(OH)COO}\\ |\\ \text{CH(OH)COO}\end{array}\!\Big\rangle Ca + 2KCl$$

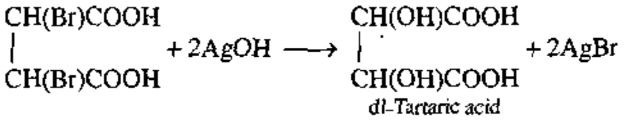
Potassium tartarate — Calcium tartarate

Both lots of calcium tartarate are mixed and then decomposed with calculated amount of dilute H_2SO_4. $CaSO_4$ is filtered off and the filterate after decolourisation with animal charcoal, is evaporated under reduced pressure to get crystals of *d*-tartaric acid.



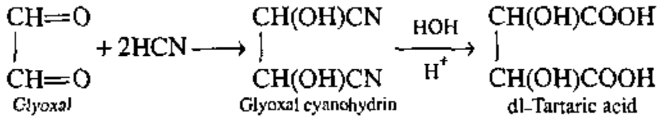
$$\begin{array}{l}CH(OH)COO\\ |\\ CH(OH)COO\end{array}\!>\!Ca + H_2SO_4\ (\text{Dilute}) \rightarrow \underset{\text{Tartaric acid}}{\begin{array}{l}CH(OH)COOH\\ |\\ CH(OH)COOH\end{array}} + CaSO_4$$

(2) By boiling α, α′-dibromo succinic acid with moist silver oxide.



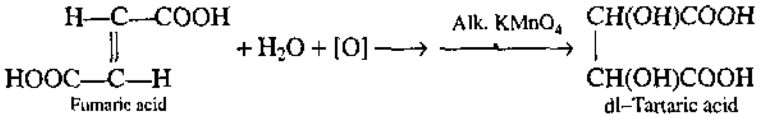
$$\begin{array}{l}CH(Br)COOH\\ |\\ CH(Br)COOH\end{array} + 2AgOH \longrightarrow \underset{dl\text{-Tartaric acid}}{\begin{array}{l}CH(OH)COOH\\ |\\ CH(OH)COOH\end{array}} + 2AgBr$$

(3) By treatment of glyoxal with HCN.

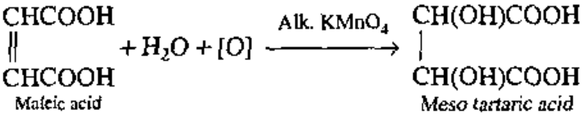


$$\underset{\text{Glyoxal}}{\begin{array}{l}CH{=}O\\ |\\ CH{=}O\end{array}} + 2HCN \longrightarrow \underset{\text{Glyoxal cyanohydrin}}{\begin{array}{l}CH(OH)CN\\ |\\ CH(OH)CN\end{array}} \xrightarrow[H^+]{HOH} \underset{\text{dl-Tartaric acid}}{\begin{array}{l}CH(OH)COOH\\ |\\ CH(OH)COOH\end{array}}$$

(4) By the oxidation of fumaric acid or maleic acid with alkaline $KMnO_4$.

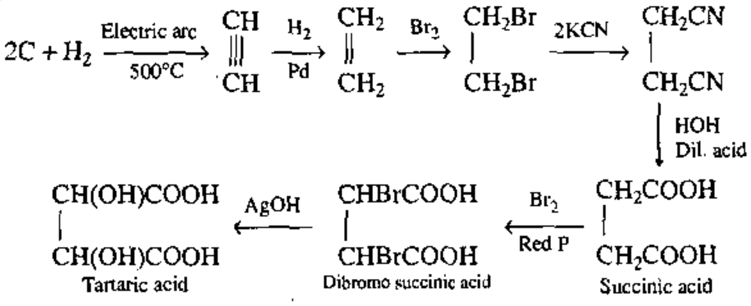


$$\underset{\text{Fumaric acid}}{\begin{array}{r}H{-}C{-}COOH\\ \|\ \ \ \ \ \ \ \\ HOOC{-}C{-}H\ \ \ \ \ \ \end{array}} + H_2O + [O] \longrightarrow \xrightarrow{\text{Alk. }KMnO_4} \underset{\text{dl-Tartaric acid}}{\begin{array}{l}CH(OH)COOH\\ |\\ CH(OH)COOH\end{array}}$$



$$\underset{\text{Maleic acid}}{\begin{array}{l}CHCOOH\\ \|\\ CHCOOH\end{array}} + H_2O + [O] \xrightarrow{\text{Alk. }KMnO_4} \underset{\textit{Meso tartaric acid}}{\begin{array}{l}CH(OH)COOH\\ |\\ CH(OH)COOH\end{array}}$$

(5) By synthesis.



$$2C + H_2 \xrightarrow[500°C]{\text{Electric arc}} \begin{array}{l}CH\\ |||\\ CH\end{array} \xrightarrow[Pd]{H_2} \begin{array}{l}CH_2\\ \|\\ CH_2\end{array} \xrightarrow{Br_2} \begin{array}{l}CH_2Br\\ |\\ CH_2Br\end{array} \xrightarrow{2KCN} \begin{array}{l}CH_2CN\\ |\\ CH_2CN\end{array}$$

$$\begin{array}{l}CH_2CN\\ |\\ CH_2CN\end{array} \xrightarrow[\text{Dil. acid}]{HOH} \underset{\text{Succinic acid}}{\begin{array}{l}CH_2COOH\\ |\\ CH_2COOH\end{array}} \xrightarrow[\text{Red P}]{Br_2} \underset{\text{Dibromo succinic acid}}{\begin{array}{l}CHBrCOOH\\ |\\ CHBrCOOH\end{array}} \xrightarrow{AgOH} \underset{\text{Tartaric acid}}{\begin{array}{l}CH(OH)COOH\\ |\\ CH(OH)COOH\end{array}}$$

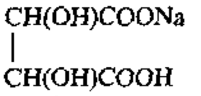
[II] Physical Properties

Tartaric acid is a colourless crystalline solid, M.P. = 171°C, soluble in water and alcohol, but insoluble in ether. Since it has two asymmetric carbon atoms, it shows optical isomerism. The natural tartaric acid is the dextro variety and angle of rotation, *i.e.*,

$$[\alpha]_D^{20} = +12.7°.$$

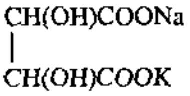
[III] Chemical Properties

(1) Action of alkali. Tartaric acid forms two series of salts, *i.e.*, acid salt and normal salt, *e.g.*,



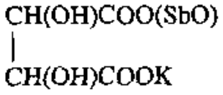
$$\begin{array}{l}CH(OH)COONa\\ |\\ CH(OH)COOH\end{array}$$

Sodium hydrogen tartarate
(Acid salt)



$$\begin{array}{l}CH(OH)COONa\\ |\\ CH(OH)COOK\end{array}$$

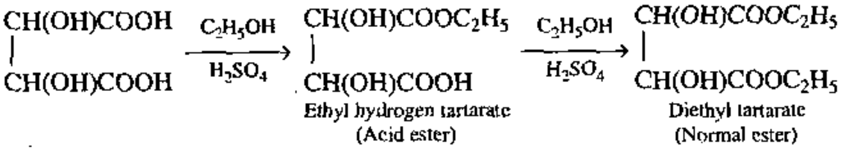
Rochelle salt
(Sodium potassium tartarate)



$$\begin{array}{l}CH(OH)COO(SbO)\\ |\\ CH(OH)COOK\end{array}$$

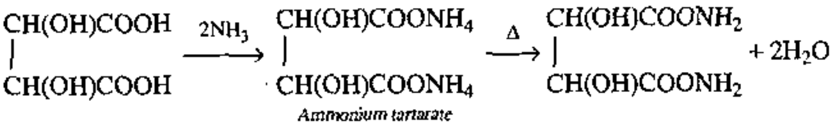
Potassium antimonyl tartarate
(Tartar emetic)

(2) Action of alcohol. With alcohols, tartaric acid forms acid and normal esters.



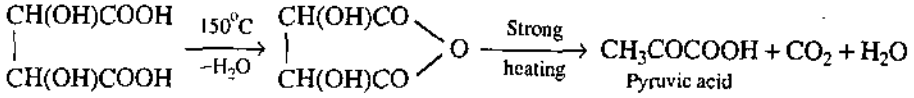
$$\begin{array}{l}CH(OH)COOH\\ |\\ CH(OH)COOH\end{array} \xrightarrow[H_2SO_4]{C_2H_5OH} \underset{\substack{\text{Ethyl hydrogen tartarate}\\ \text{(Acid ester)}}}{\begin{array}{l}CH(OH)COOC_2H_5\\ |\\ CH(OH)COOH\end{array}} \xrightarrow[H_2SO_4]{C_2H_5OH} \underset{\substack{\text{Diethyl tartarate}\\ \text{(Normal ester)}}}{\begin{array}{l}CH(OH)COOC_2H_5\\ |\\ CH(OH)COOC_2H_5\end{array}}$$

(3) Action of ammonia. Tartaric acid forms ammonium salt, which changes to amide on heating.



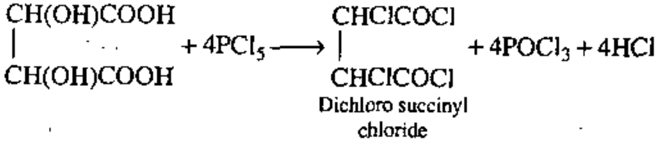
$$\begin{array}{l}CH(OH)COOH\\ |\\ CH(OH)COOH\end{array} \xrightarrow{2NH_3} \underset{\textit{Ammonium tartarate}}{\begin{array}{l}CH(OH)COONH_4\\ |\\ CH(OH)COONH_4\end{array}} \xrightarrow{\Delta} \begin{array}{l}CH(OH)COONH_2\\ |\\ CH(OH)COONH_2\end{array} + 2H_2O$$

(4) Action of heat. When heated at 150°C, tartaric acid forms anhydride. On strong heating *i.e.*, above 170°C it chars with the formation of pyruvic acid.



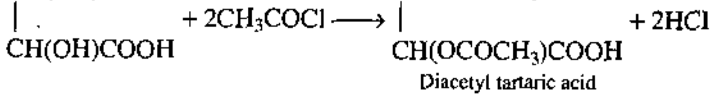
$$\begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{CH(OH)COOH}\end{array} \xrightarrow[-H_2O]{150^\circ C} \begin{array}{l}\text{CH(OH)CO}\\ |\\ \text{CH(OH)CO}\end{array}\!\!>\!O \xrightarrow[\text{heating}]{\text{Strong}} \underset{\text{Pyruvic acid}}{CH_3COCOOH} + CO_2 + H_2O$$

(5) Action of PCl_5. Tartaric acid forms dichloro succinyl chloride.



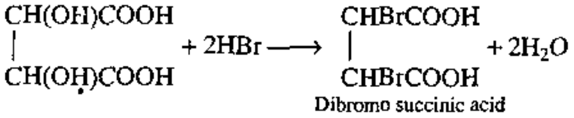
$$\begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{CH(OH)COOH}\end{array} + 4PCl_5 \longrightarrow \underset{\text{Dichloro succinyl chloride}}{\begin{array}{l}\text{CHClCOCl}\\ |\\ \text{CHClCOCl}\end{array}} + 4POCl_3 + 4HCl$$

(6) Action of CH_3COCl. Tartaric acid forms diacetyl tartaric acid.



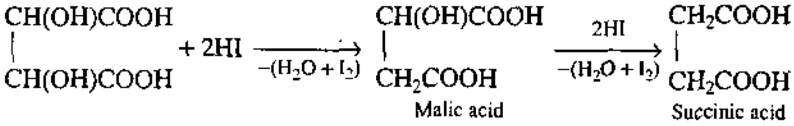
$$\begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{CH(OH)COOH}\end{array} + 2CH_3COCl \longrightarrow \underset{\text{Diacetyl tartaric acid}}{\begin{array}{l}\text{CH(OCOCH}_3\text{)COOH}\\ |\\ \text{CH(OCOCH}_3\text{)COOH}\end{array}} + 2HCl$$

(7) Action of HBr. Tartaric acid forms dibromo succinic acid.



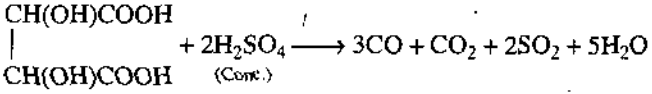
$$\begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{CH(OH)COOH}\end{array} + 2HBr \longrightarrow \underset{\text{Dibromo succinic acid}}{\begin{array}{l}\text{CHBrCOOH}\\ |\\ \text{CHBrCOOH}\end{array}} + 2H_2O$$

(8) Action of HI. Tartaric acid forms malic acid and then gives succinic acid.



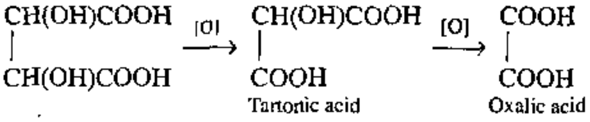
$$\begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{CH(OH)COOH}\end{array} + 2HI \xrightarrow[-(H_2O+I_2)]{} \underset{\text{Malic acid}}{\begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{CH}_2\text{COOH}\end{array}} \xrightarrow[-(H_2O+I_2)]{2HI} \underset{\text{Succinic acid}}{\begin{array}{l}\text{CH}_2\text{COOH}\\ |\\ \text{CH}_2\text{COOH}\end{array}}$$

(9) Action of conc. H_2SO_4. Tartaric acid decomposes into carbon monoxide, CO_2, SO_2 etc.



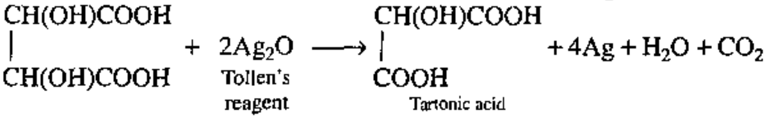
$$\begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{CH(OH)COOH}\end{array} + \underset{\text{(Conc.)}}{2H_2SO_4} \longrightarrow 3CO + CO_2 + 2SO_2 + 5H_2O$$

(10) Oxidation. (a) With mild oxidising agents, tartaric acid is oxidised to tartonic acid, while with strong oxidising agents, *e.g.*, conc. HNO_3, it forms oxalic acid.



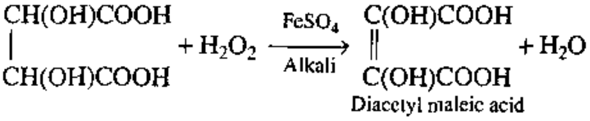
$$\begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{CH(OH)COOH}\end{array} \xrightarrow{[O]} \underset{\text{Tartonic acid}}{\begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{COOH}\end{array}} \xrightarrow{[O]} \underset{\text{Oxalic acid}}{\begin{array}{l}\text{COOH}\\ |\\ \text{COOH}\end{array}}$$

(b) Action of Tollen's reagent. Since tartaric acid is easily oxidised with mild oxidising agents, it acts as a reducing agent and forms silver mirror with Tollen's reagent.



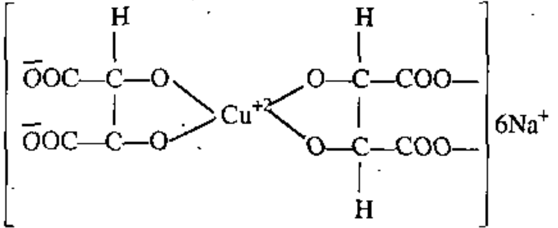
$$\begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{CH(OH)COOH}\end{array} + \underset{\text{Tollen's reagent}}{2Ag_2O} \longrightarrow \underset{\text{Tartonic acid}}{\begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{COOH}\end{array}} + 4Ag + H_2O + CO_2$$

(c) Action of Fenton's reagent. When tartaric acid is oxidised with Fenton's reagent (Alk. $H_2O_2 + FeSO_4$) dihydroxy maleic acid is formed.



$$\begin{array}{l}\text{CH(OH)COOH}\\ |\\ \text{CH(OH)COOH}\end{array} + H_2O_2 \xrightarrow[\text{Alkali}]{FeSO_4} \underset{\text{Diacetyl maleic acid}}{\begin{array}{l}\text{C(OH)COOH}\\ \|\\ \text{C(OH)COOH}\end{array}} + H_2O$$

(11) Complex formation. In Fehling's solution ($CuSO_4$ + Rochelle salt + NaOH) sodium potassium tartarate checks the precipitation of insoluble copper hydroxide by converting the latter into soluble complex with the following probable structure.



Sodium cupritartarate

[IV] Uses

Tartaric acid is used :

(1) In the preparation of effervescent and saline drinks.

(2) In preparing potassium antimonyl tartarate which is used to cause nausea and vomiting in the treatment of poisoning.

(3) As a mordant in dyeing and calicoprinting.

(4) In preparing potassium acid tartarate which is used in baking powder and dyeing..

[V] Structure of Tartaric acid

(a) Molecular formula. The molecular formula of tartaric acid is $C_4H_6O_6$.

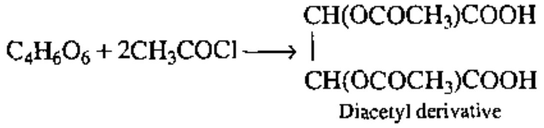
(b) Presence of two carboxylic groups. Tartaric acid gives two series of salts and esters. Hence, it contains two carboxylic (—COOH) groups.

$$C_4H_6O_6 + NaOH \rightarrow C_4H_5O_6Na \xrightarrow{NaOH} C_4H_4O_6Na_2$$

$$C_4H_6O_6 + C_2H_5OH \rightarrow C_4H_5O_6C_2H_5 \xrightarrow{C_2H_5OH} \underset{\text{Ethyl tartarate}}{C_4H_4O_6\,(C_2H_5)_2}$$

On heating, tartaric acid does not give CO_2. Hence, the two —COOH groups must be linked to two different carbon atoms.

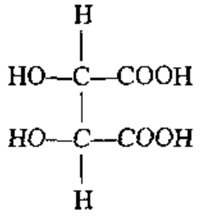
(c) Presence of two hydroxyl groups. It is indicated by the formation of diacetyl derivatives and dibromo derivatives with acetyl chloride and bromine (in presence of red P), respectively. Since the acid is stable, hence the two —OH groups *must be linked to two different carbon atoms.*



$$C_4H_6O_6 + 2CH_3COCl \longrightarrow \begin{array}{l} CH(OCOCH_3)COOH \\ | \\ CH(OCOCH_3)COOH \end{array}$$

Diacetyl derivative

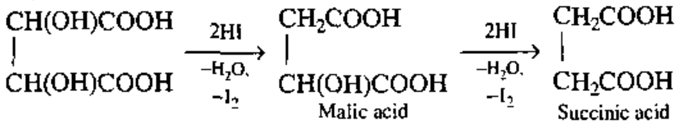
(d) In view of the above mentioned facts and considering the valencies of different elements, tartaric acid should be represented by the following structure.



$$\begin{array}{c} H \\ | \\ HO\text{—}C\text{—}COOH \\ | \\ HO\text{—}C\text{—}COOH \\ | \\ H \end{array}$$

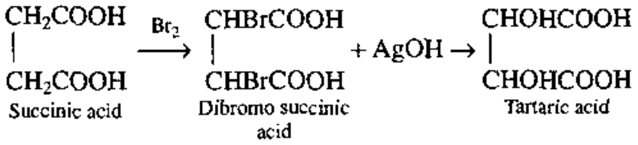
(e) The above reaction is confirmed by the following reactions :

(i) On reduction with HI, tartaric acid yields malic acid and succinic acid. This shows that tartaric acid is dihydroxy succinic acid.



$$\begin{array}{l} CH(OH)COOH \\ | \\ CH(OH)COOH \end{array} \xrightarrow[-H_2O,\ -I_2]{2HI} \underset{\text{Malic acid}}{\begin{array}{l} CH_2COOH \\ | \\ CH(OH)COOH \end{array}} \xrightarrow[-H_2O,\ -I_2]{2HI} \underset{\text{Succinic acid}}{\begin{array}{l} CH_2COOH \\ | \\ CH_2COOH \end{array}}$$

(ii) Formation of tartaric acid from dibromo succinic acid with AgOH confirms the above view.



$$\underset{\text{Succinic acid}}{\begin{array}{l} CH_2COOH \\ | \\ CH_2COOH \end{array}} \xrightarrow{Br_2} \underset{\text{Dibromo succinic acid}}{\begin{array}{l} CHBrCOOH \\ | \\ CHBrCOOH \end{array}} + AgOH \rightarrow \underset{\text{Tartaric acid}}{\begin{array}{l} CHOHCOOH \\ | \\ CHOHCOOH \end{array}}$$

The above structure of tartaric acid is further confirmed by its synthesis.

• 2.6. CITRIC ACID

[I] Methods of Preparation

(1) From lemon juice. The unripe lemons are squeezed to get the juice. Following method is followed in the recovery of citric acid from lemon juice.

(a) Lemon juice is boiled to coagulate the proteins present in it and then filtered.

(b) The filterate is neutralized with $CaCO_3$ and boiled when tricalcium citrate precipitates out.

$$\underset{\text{Citric acid}}{2C_6H_8O_7} + 3CaCO_3 \longrightarrow \underset{\text{Tricalcium citrate}}{Ca_3(C_6H_5O_7)_2} + 3H_2O + 3CO_2$$

(c) The white precipitate of tricalcium citrate is filtered and decomposed with a calculated amount of dil. H_2SO_4. A white precipitate of $CaSO_4$ is formed, which is removed by filteration.

$$Ca_3(C_6H_5O_7)_2 + 3H_2SO_4 \longrightarrow \underset{\text{Citric acid}}{2C_6H_8O_7} + \underset{\text{White ppt.}}{3CaSO_4}$$

(d) The filterate containing citric acid on concentration by evaporation deposits crystals of citric acid. These are further purified by recrystallization to get the crystals of monohydrate of citric acid ($C_6H_8O_7 . H_2O$).

(2) From fermentation of sugars. This method was introduced in U.S.A. It is now widely used for the manufacture of citric acid in U.S.A., U.K. and Japan.

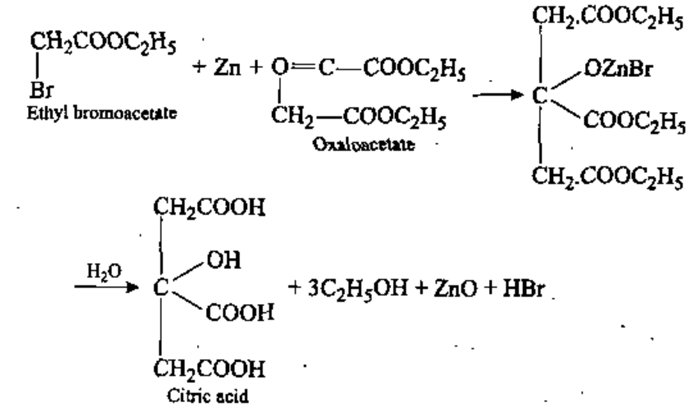
A dilute solution of molasses, glucose or sucrose is fermented with certain moulds or fungi, *e.g., citromyces, pfeffarianus,* and *aspergillus niger* at 40°C in presence of certain inorganic salts like $CaCO_3$ which neutralize the free acid formed during fermentation as the fungi do not grow in highly acidic medium. Citric acid is formed within 7–10 days.

$$\underset{\text{Cane sugar}}{C_{12}H_{22}O_{11}} + 3O_2 \xrightarrow[40^\circ C]{\text{Aspergillus niger}} 2C_6H_8O_7 + 3H_2O$$

$$C_6H_{12}O_6 + 3\,[O] \longrightarrow C_6H_8O_7 + 2H_2O$$

$$\underset{\text{Citric acid}}{2C_6H_8O_7} + 3CaCO_3 \longrightarrow \underset{\text{Tricalcium citrate}}{Ca_3(C_6H_5O_7)_2} + 3H_2O + 3CO_2$$

$$\underset{\text{Tricalcium citrate}}{Ca_3(C_6H_5O_7)_2} + 3H_2SO_4 \longrightarrow \underset{\text{Citric acid}}{2C_6H_8O_7} + \underset{\text{White ppt}}{3CaSO_4\downarrow}$$



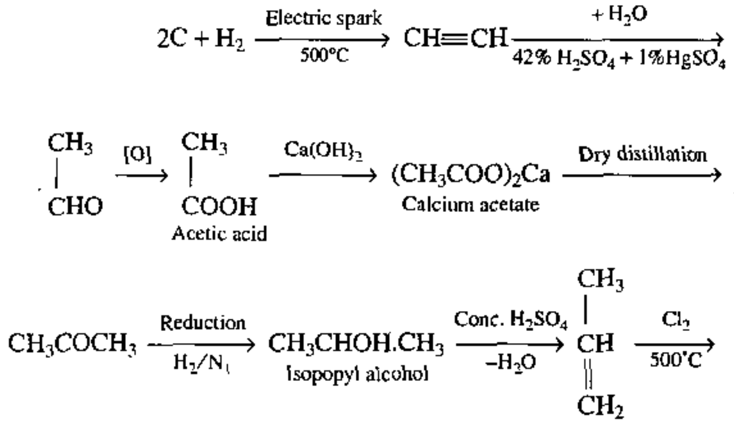
$$\underset{\text{Ethyl bromoacetate}}{\begin{array}{l}CH_2COOC_2H_5\\ |\\ Br\end{array}} + Zn + \underset{\text{Oxaloacetate}}{\begin{array}{l}O{=}C{-}COOC_2H_5\\ |\\ CH_2{-}COOC_2H_5\end{array}} \longrightarrow \begin{array}{l}CH_2.COOC_2H_5\\ |\\ C\begin{array}{l}\diagup OZnBr\\ \diagdown COOC_2H_5\end{array}\\ |\\ CH_2.COOC_2H_5\end{array}$$

$$\xrightarrow{H_2O} \underset{\text{Citric acid}}{\begin{array}{l}CH_2COOH\\ |\\ C\begin{array}{l}\diagup OH\\ \diagdown COOH\end{array}\\ |\\ CH_2COOH\end{array}} + 3C_2H_5OH + ZnO + HBr$$

(3) By Reformatsky's reaction. By hydrolysing the product obtained during the condensation of ethyl bromoacetate with oxaloacetate in presence of zinc.

(4) From petroleum. Recently, it has been shown that certain strains of candida (a yeast) can produce citric acid from *n*-alkanes derived from petroleum. This method when developed will revolutionise the citric acid industry.

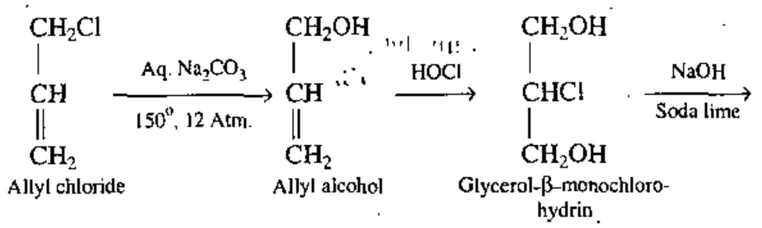
(5) From synthesis. Citric acid can be synthesised as follows :

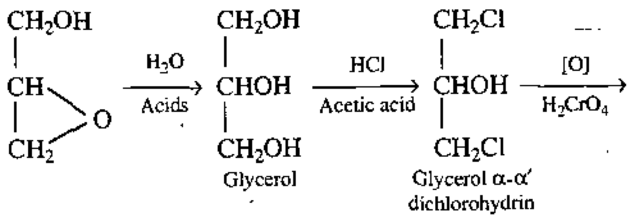


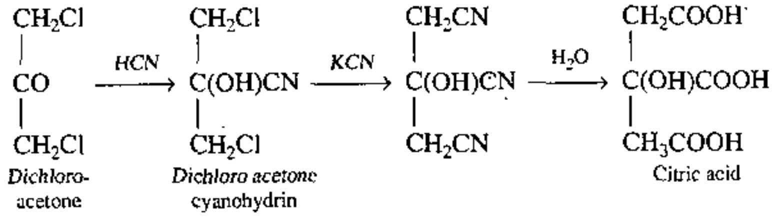
$$2C + H_2 \xrightarrow[500^\circ C]{\text{Electric spark}} CH{\equiv}CH \xrightarrow[42\%\ H_2SO_4 + 1\%HgSO_4]{+H_2O}$$

$$\begin{array}{c}CH_3\\ |\\ CHO\end{array} \xrightarrow{[O]} \underset{\text{Acetic acid}}{\begin{array}{c}CH_3\\ |\\ COOH\end{array}} \xrightarrow{Ca(OH)_2} \underset{\text{Calcium acetate}}{(CH_3COO)_2Ca} \xrightarrow{\text{Dry distillation}}$$

$$CH_3COCH_3 \xrightarrow[H_2/Ni]{\text{Reduction}} \underset{\text{Isopopyl alcohol}}{CH_3CHOH.CH_3} \xrightarrow[-H_2O]{\text{Conc. }H_2SO_4} \begin{array}{c}CH_3\\ |\\ CH\\ \|\\ CH_2\end{array} \xrightarrow[500^\circ C]{Cl_2}$$







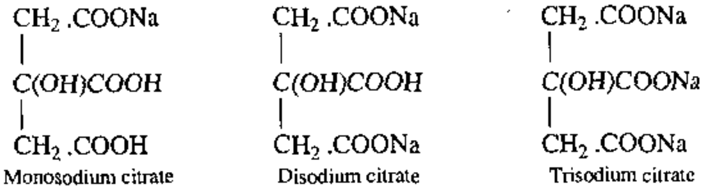
Ans-3

[II] Physical Properties

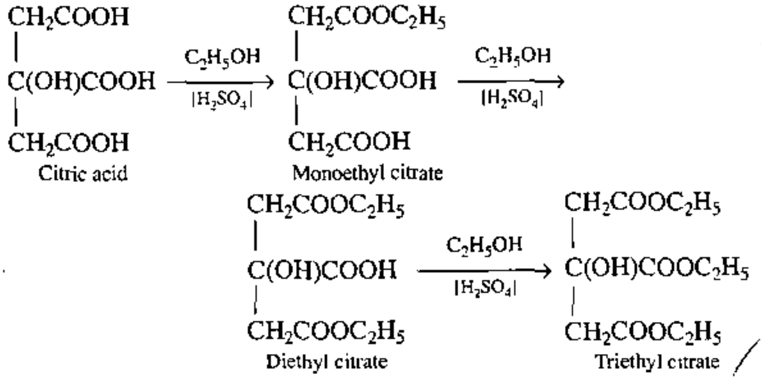
Citric acid crystallises in the form of large rhombic crystals containing one molecule of water of crystallisation. The melting point of hydrous acid is 101°C and that of anhydrous 153°C. It is highly soluble in water and alcohol but less soluble in ether.

[III] Chemical Properties

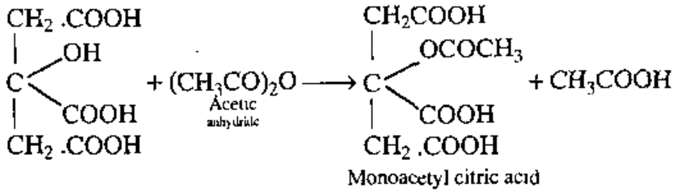
(1) Action of alkali. Citric acid forms three series of salts.



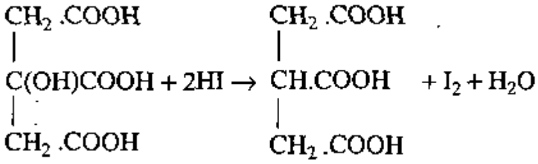
(2) Action of alcohol. Citric acid forms three series of esters.



(3) Action of acetyl chloride. With acetyl chloride or acetic anhydride, citric acid forms monoacetyl derivative.



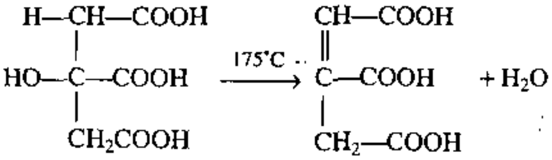
(4) Action of HI. Citric acid gives tricarballylic acid.



$$CH_2COOH{-}C(OH)(COOH){-}CH_2COOH + 2HI \rightarrow CH_2COOH{-}CH(COOH){-}CH_2COOH + I_2 + H_2O$$

Citric acid — Tricarballylic acid

(5) Action of heat. When citric acid is heated at 175°C, it gives aconitic acid.

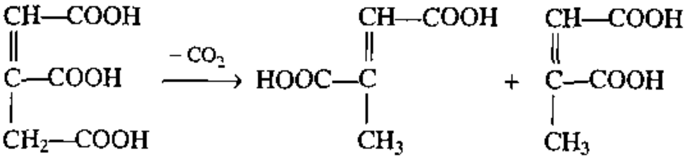


$$H{-}CH(COOH){-}C(OH)(COOH){-}CH_2COOH \xrightarrow{175°C} CH(COOH){=}C(COOH){-}CH_2{-}COOH + H_2O$$

Citric acid — Aconitic acid

Aconitic acid readily loses cabon dioxide at higher temperatures producing isomeric citraconic, mesaconic and itaconic acid. Citraconic and itaconic acids then lose water to produce their respective anhydrides.

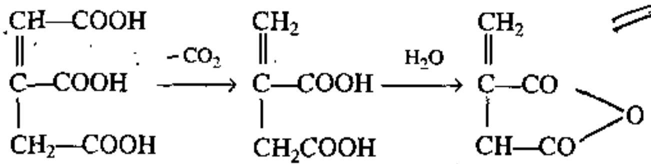
(i)



$$CH(COOH){=}C(COOH){-}CH_2{-}COOH \xrightarrow{-CO_2} HOOC{-}C(CH_3){=}CH{-}COOH + CH(COOH){=}C(COOH){-}CH_3$$

Aconitic acid — Mesaconic acid (Trans form) — Citraconic acid (Cis form)

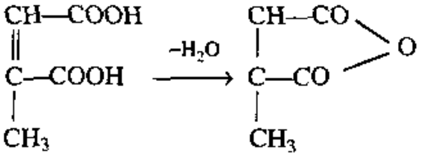
(ii)



$$CH(COOH){=}C(COOH){-}CH_2{-}COOH \xrightarrow{-CO_2} CH_2{=}C(COOH){-}CH_2COOH \xrightarrow{H_2O} \text{Itaconic anhydride}$$

Aconitic acid — Itaconic acid — Itaconic anhydride

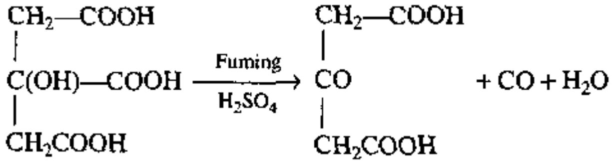
(iii)



$$CH(COOH){=}C(COOH){-}CH_3 \xrightarrow{-H_2O} \text{Citraconic anhydride}$$

Citraconic acid (Cis acid) — Citraconic anhydride

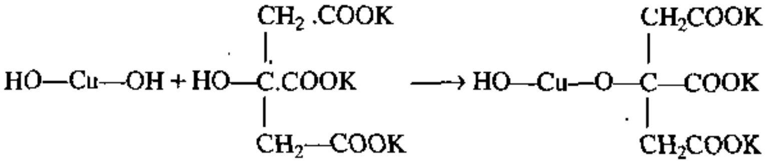
(6) Action of sulphuric acid : When citric acid is heated with fuming H_2SO_4 it gives dicarboxylic acid.



$$CH_2{-}COOH{-}C(OH){-}COOH{-}CH_2COOH \xrightarrow[H_2SO_4]{Fuming} CH_2{-}COOH{-}CO{-}CH_2COOH + CO + H_2O$$

Citric acid (Cis acid) — Acetone dicarboxylic acid

(7) Action of metallic hydroxides : Citric acid forms soluble salts with certain metallic hydroxides *e.g.*, $Cu(OH)_2$.



$$HO{-}Cu{-}OH + HO{-}C(CH_2COOK)(CH_2{-}COOK){-}COOK \rightarrow HO{-}Cu{-}O{-}C(CH_2COOK)(CH_2COOK){-}COOK$$

Soluble complex

[IV] Uses

Citric acid is used :

(i) As a mordant in dyeing and painting.

(ii) In confectionery and synthetic fruit drinks.

(iii) In preparing magnesium citrate which is used as a laxative in medicine.

(iv) In preparing ferric ammonium ciitate which is used in preparing blue prints. It is also used in medicine for iron deficiency.

(v) In preparing esters like tributyl citrate which is used as a solvent in plastic industry.

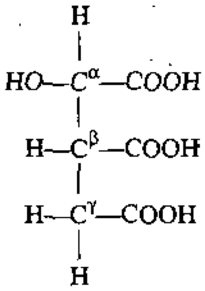
[V] Structure of Citric Acid

(a) Molecular formula. The molecular formula of citric acid is $C_6H_8O_7$.

(b) Presence of three carboxylic groups. Formation of three series of salts and esters indicates that citric acid has three carboxyl groups. Since CO_2 is not lost on heating, so three —COOH groups must be present on three different carbon atoms.

(c) Presence and position of one hydroxyl group. Citric acid forms monoacetyl derivative with acetyl chloride which shows the presence of only one —OH group.

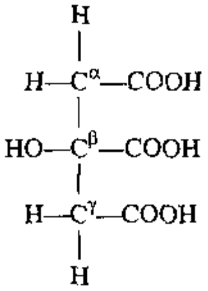
(d) Probable structure. In view of the above facts, citric acid may have any of the following structures :



$$\begin{array}{c} H \\ | \\ HO—C^{\alpha}—COOH \\ | \\ H—C^{\beta}—COOH \\ | \\ H—C^{\gamma}—COOH \\ | \\ H \end{array}$$

I

(OH group attached to α- carbon atom)



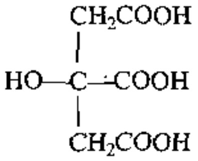
$$\begin{array}{c} H \\ | \\ H—C^{\alpha}—COOH \\ | \\ HO—C^{\beta}—COOH \\ | \\ H—C^{\gamma}—COOH \\ | \\ H \end{array}$$

II

(—OH group attached to β-carbon atom)

(e) Citric acid on heating yields aconitic acid, the formation of which can be explained by both the structures I and II. However, the formation of acetone dicarboxylic acid, by heating citric acid with fuming H_2SO_4, can be explained only by structure II.

Hence, the structure of citric acid may be written as



$$\begin{array}{c} CH_2COOH \\ | \\ HO—C—COOH \\ | \\ CH_2COOH \end{array}$$

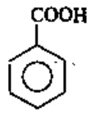
(f) This structure has also been confirmed by its synthesis as mentioned before.

2.7. AROMATIC CARBOXYLIC ACIDS

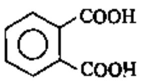
Introduction

Aromatic carboxylic acids are obtained by the replacement of one or more hydrogen atoms of benzene nucleus by carboxylic (—COOH) groups. The —COOH group may be present in the nucleus or in the side chain.

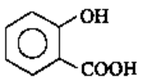
(a) —COOH group in the nucleus : In these compounds, —COOH group is attached directly to the benzene nucleus. The acids may be mono basic, dibasic or tribasic depending upon the number of —COOH groups present. Besides this, other groups may also be present in the benzene nucleus.



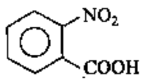
Benzoic acid



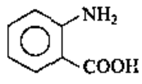
Phthalic acid



Salicylic acid
(o-Hydroxy benzoic acid)

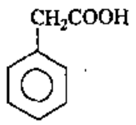


o-Nitrobenzoic acid

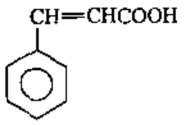


Anthranilic acid
(o-Amino benzoic acid)

(b) —COOH group in the side chain : In these compounds, —COOH groups are present in the side chain. For example,



Phenyl acetic acid

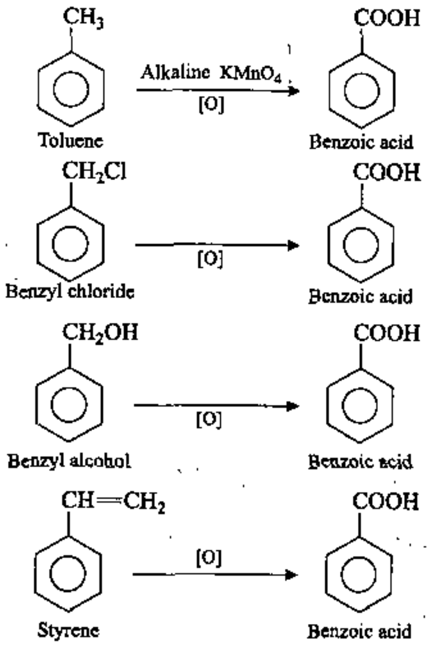


Cinnamic acid

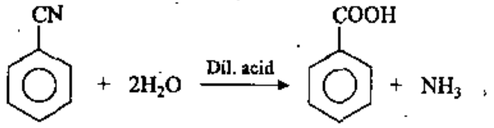
2.8. BENZOIC ACID

[I] Preparation

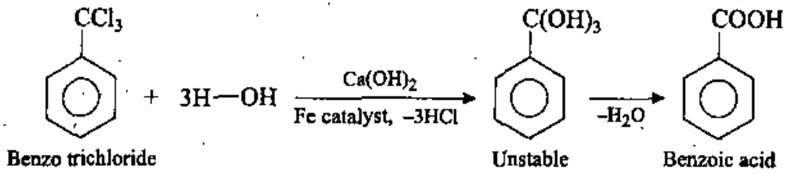
(i) Benzoic acid is prepared by the oxidation of aromatic compounds containing aliphatic side chains with alkaline $KMnO_4$ or dil. HNO_3 or $K_2Cr_2O_7$ and dil. H_2SO_4



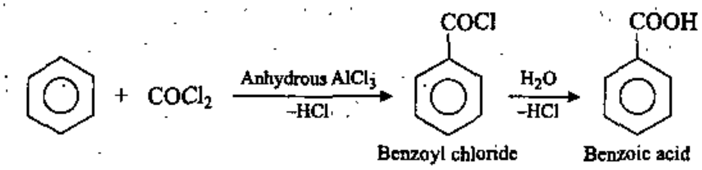
(ii) Benzoic acid is prepared by the hydrolysis of cyanobenzene.



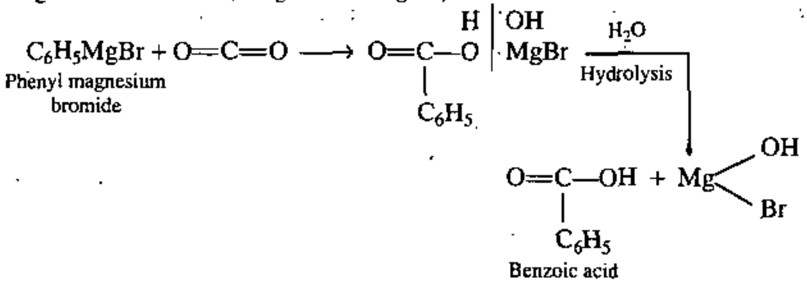
(iii) Benzoic acid is prepared by the hydrolysis of benzotrichloride with $Ca(OH)_2$ in the presence of iron powder. (*Manufacture*).



(iv) Benzoic acid is prepared by the hydrolysis of benzoyl chloride obtained by the action of carbonyl chloride on benzene in the presence of anhydrous $AlCl_3$.

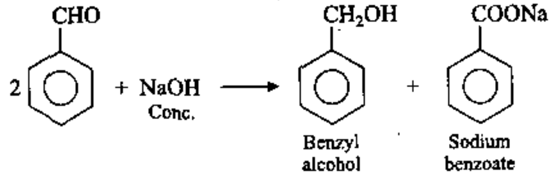


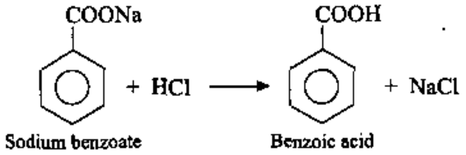
(v) Benzoic acid is prepared by the hydrolysis of compound obtained by the reaction of CO_2 on phenyl magnesium bromide *(Grignard's reagent)*.



$$\underset{\text{Phenyl magnesium bromide}}{C_6H_5MgBr} + O{=}C{=}O \longrightarrow O{=}\underset{C_6H_5}{C}{-}O\,\overset{H\ |\ OH}{|\,MgBr} \xrightarrow[\text{Hydrolysis}]{H_2O} \underset{\text{Benzoic acid}}{O{=}\underset{C_6H_5}{C}{-}OH} + Mg\begin{matrix} OH \\ Br \end{matrix}$$

(vi) Benzoic acid is prepared by the action of dil. HCl on sodium benzoate obtained by the action of conc. NaOH on benzaldehyde.





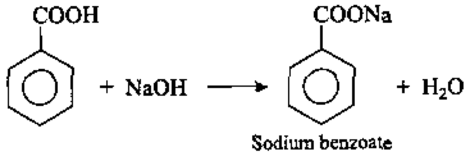
[II] Physical Properties

Benzoic acid is a white crystalline solid, M.Pt. 122°C. It sublimes even before its melting point. It is sparingly soluble in cold water, but is soluble in hot water, alcohol and ether.

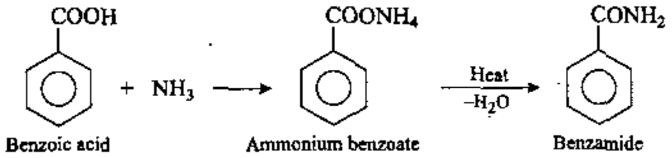
[III] Chemical Properties

(1) Reactions Due to —COOH Group

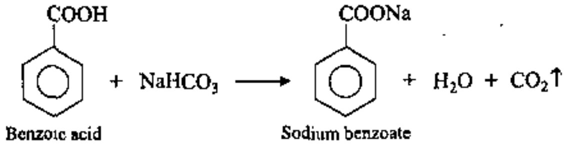
(i) Action with alkalies : Benzoic acid reacts with alkalies to form salts.

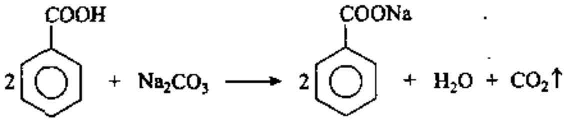


(ii) Action with NH_3 : Ammonium benzoate is formed which on heating forms benzamide.

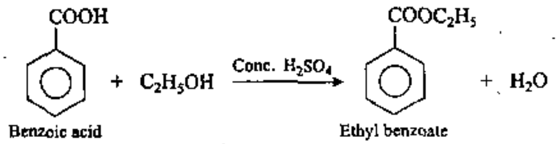


(iii) Action with carbonate salts : Benzoic acid decomposes carbonate salts to form CO_2.

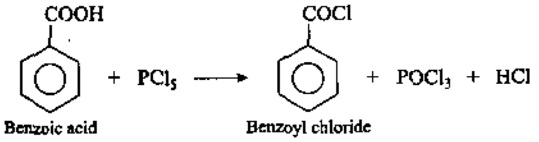




(iv) Action with alcohol : Ester is formed.



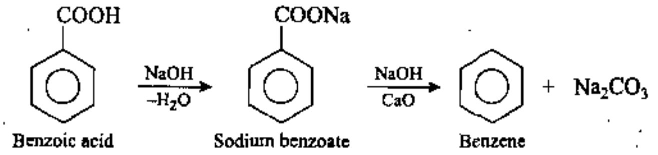
(v) Action with PCl_5 : Benzoyl chloride is formed.



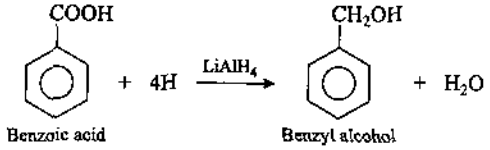
(vi) Dehydration : On heating benzoic acid with acetic anhydride, benzoic anhydride is formed.

$$2C_6H_5COOH \xrightarrow[-H_2O]{(CH_3CO)_2O} \underset{\text{Benzoic anhydride}}{(C_6H_5CO)_2O}$$

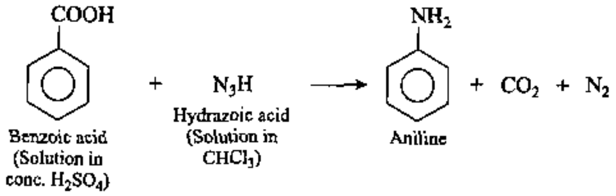
(vii) Decarboxylation : On heating with soda lime, benzoic acid forms benzene.



(viii) Reduction : On reduction with $LiAlH_4$, benzoic acid forms benzyl alcohol.



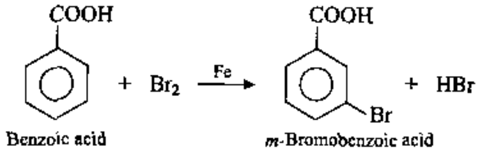
(ix) Schmidt reaction : The solution of benzoic acid in H_2SO_4 reacts with hydrazoic acid in $CHCl_3$ to form aniline.



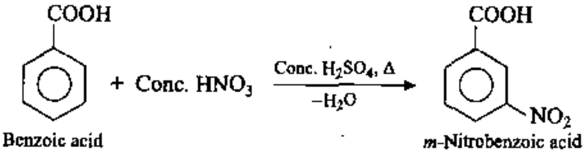
(2) Reactions Due to Benzene Nucleus

The directive influence of —COOH group is meta directing. Hence, on halogenation, nitration and sulphonation, benzoic acid gives meta substituted derivatives as shown below.

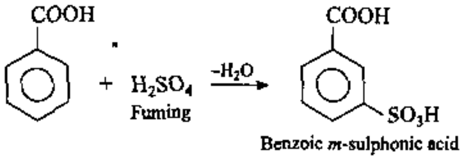
(a) Halogenation :



(b) Nitration :



(c) Sulphonation :



[IV] Uses

(i) Sodium benzoate is used in the preservation of food stuffs.

(ii) Benzoic acid and some of its compounds are used in the form of medicines.

(iii) Benzoic acid is used in the formation of aniline blue dye and its esters are used in the formation of perfumes.

• 2.9. CONVERSIONS OF BENZOIC ACID

(i) Benzophenone

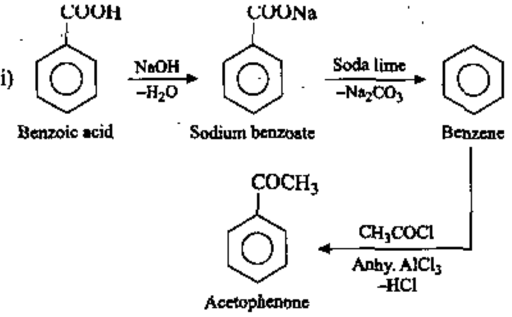
$$2C_6H_5COOH + Ca(OH)_2 \xrightarrow[-2H_2O]{} \underset{\text{Calcium benzoate}}{(C_6H_5COO)_2Ca} \xrightarrow[-CaCO_3]{\text{Dry distillation}} \underset{\text{Benzophenone}}{C_6H_5COC_6H_5}$$

(ii) Acetophenone

(i) $2C_6H_5COOH + Ca\ (OH)_2 \longrightarrow \underset{\text{Calcium benzoate}}{(C_6H_5COO)_2Ca} + 2H_2O$

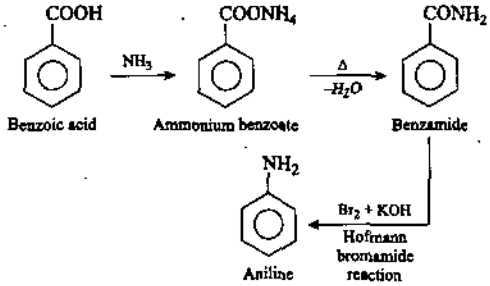
$$(C_6H_5COO)_2Ca + \underset{\text{Calcium acetate}}{(CH_3COO)_2Ca} \xrightarrow{\Delta} \underset{\text{Acetophenone}}{2C_6H_5COCH_3} + 2CaCO_3$$

(ii)

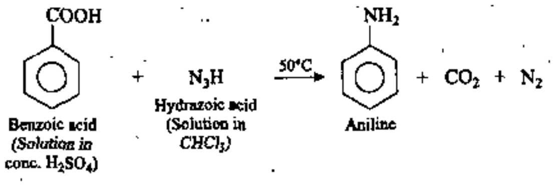


(iii) Aniline

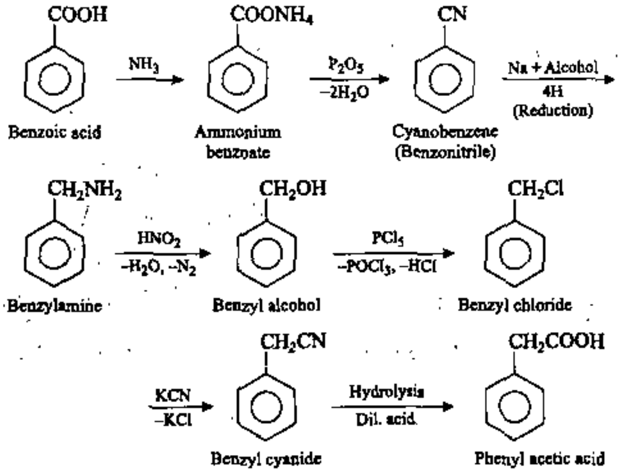
(i)



(ii)



(iv) Benzonitrile and phenyl acetic acid :



2.10. EXPLANATION OF FACTS

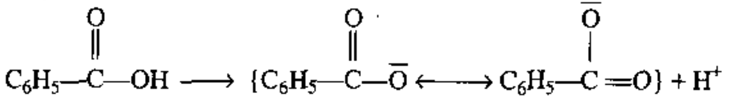
(i) *p*-Nitrobenzoic acid is stronger than m-nitrobenzoic acid. Why ?

The effect of substitutents on the acidic character of carboxylic acids can be explained on the basis of combined effects of resonance and inductive effects. Both these effects work when substitutents are present in the *o*- and *p*-positions of carboxylic group, whereas only inductive effect works when substituents are present in the meta position.

So, *p*-nitrobenzoic acid is stronger, than *m*-nitrobenzoic acid. This is due to the inductive and resonance effects of electron attracting nitro group which increases the stability of nitrobenzoate ion. As a result, the proton is easily removed from carboxylic acid. In the case of *m*-nitrobenzoic acid, the increase in the stability of nitrobenzoate ion is only due to the inductive effect of electron attracting nitro group. As a result of this the proton is not so easily removed.

(ii) *p*-Nitrobenzoic acid is stronger than benzoic acid, why ?

The acidic nature of carboxylic acids is due to their tendency to give proton in solution and stability of carboxylate ion due to resonance.



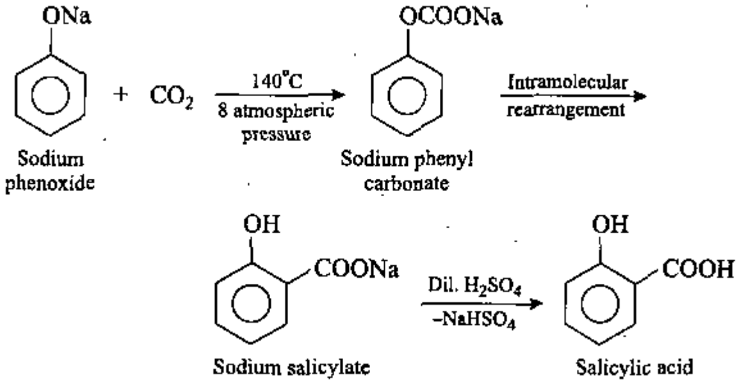
$$C_6H_5-\overset{\overset{O}{\|}}{C}-OH \longrightarrow \{C_6H_5-\overset{\overset{O}{\|}}{C}-\bar{O} \longleftrightarrow C_6H_5-\overset{\overset{\bar{O}}{|}}{C}=O\} + H^+$$

p-Nitrobenzoic acid is stronger than benzoic acid. This is due to the inductive and resonance effects of electron attracting nitro group which increase the stability of nitrobenzoate ion. As a result, the proton is easily removed from carboxylic acid.

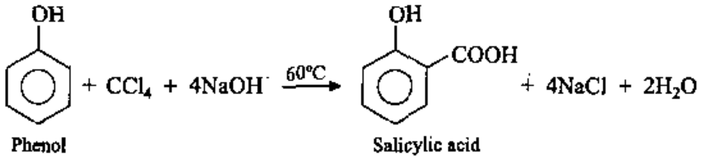
• 2.11. SALICYLIC ACID

[I] Preparation

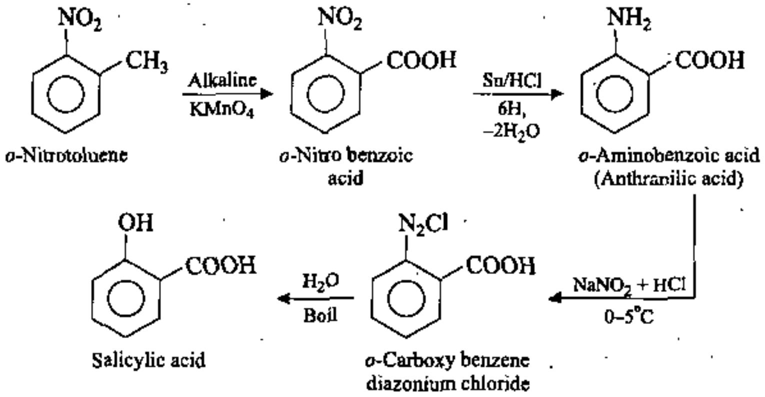
(i) From Kolbe-Schmidt reaction : Sodium salt of phenol reacts with CO_2 at 8 atmospheric pressure and at 140°C to form sodium salicylate which reacts with dil. acid to form salicylic acid. *(Manufacture).*



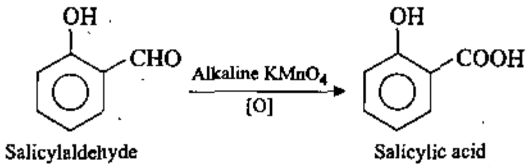
(ii) From Reimer-Tiemann reaction : Phenol reacts with CCl_4 at 60°C in presence of NaOH to give a product which when acidified gives salicylic acid as the main product.



(iii) From *o*-nitrotoluene



(iv) Salicylic acid is prepared by the oxidation of salicylaldehyde with alkaline $KMnO_4$.

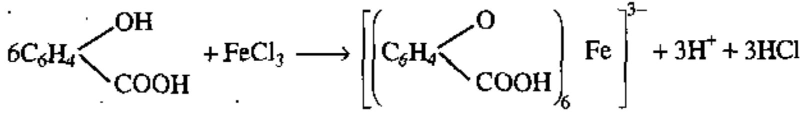


[II] Chemical Properties

Salicylic acid contains both phenolic (—OH) and carboxylic (—COOH) groups. Hence, it shows the properties of both phenol and benzoic acid.

(1) Comparison of Properties of Phenol and Salicylic Acid (Reactions due to —OH group)

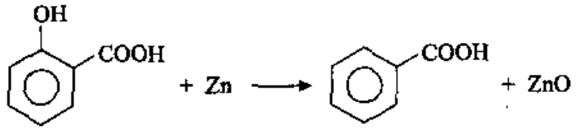
(i) Action with $FeCl_3$ solution : The aqueous solution of salicylic acid gives violet solution with 1% $FeCl_3$ solution.



$$6C_6H_4\begin{matrix}OH\\COOH\end{matrix} + FeCl_3 \longrightarrow \left[\left(C_6H_4\begin{matrix}O\\COOH\end{matrix}\right)_6 Fe\right]^{3-} + 3H^+ + 3HCl$$

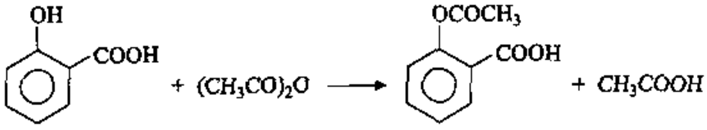
Violet solution

(ii) Action with zinc dust : Benzoic acid is formed.

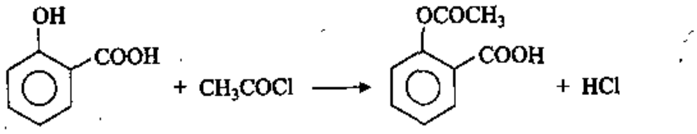


Salicylic acid　　Benzoic acid

(iii) Acetylation : Salicylic acid reacts with acetyl chloride or acetic anhydride to form acetyl salicylic acid *(aspirin)*.

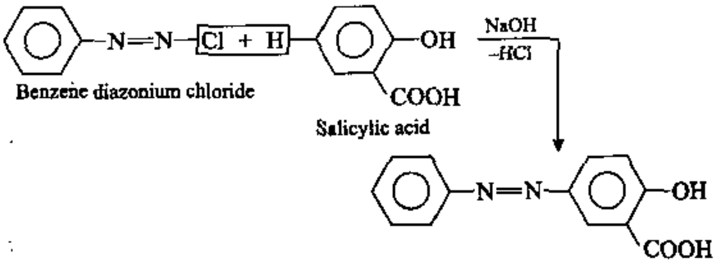


Salicylic acid　　Aspirin



Aspirin

(iv) Coupling reaction : Salicylic acid reacts with diazonium salts to form azo dyes.



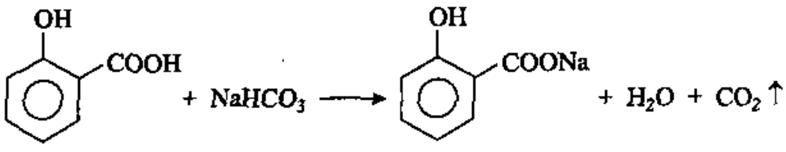
Benzene diazonium chloride

Salicylic acid

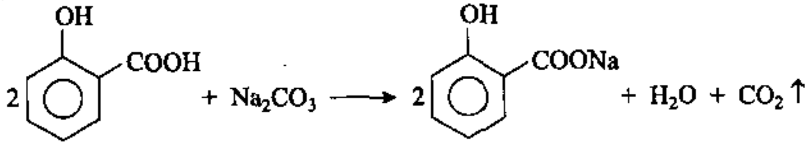
3-Carboxy-4-hydroxy azobenzene

(2) Comparison of Properties of Salicylic Acid and Benzoic Acid (Reactions due to —COOH group)

(i) Salt formation : Salicylic acid reacts with $NaHCO_3$ and Na_2CO_3 to form salt.

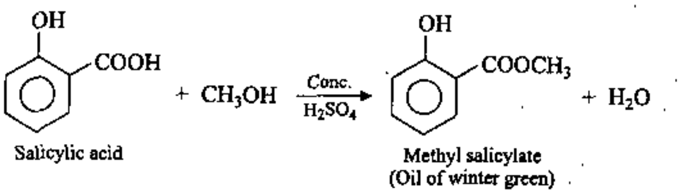


Sodium salicylate

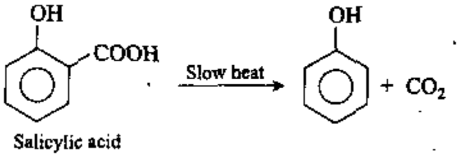


Sodium salicylate

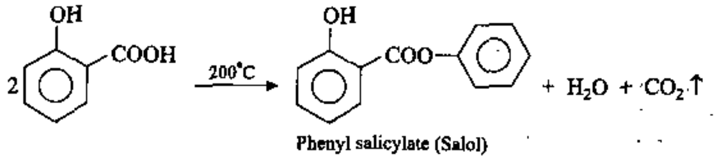
(ii) Ester formation : Salicylic acid reacts with alcohol in the presence of conc. H_2SO_4 to form ester.



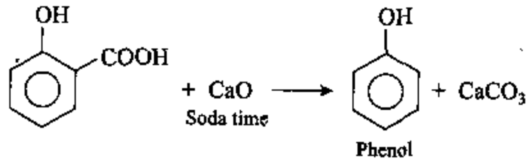
(iii) Effect of heat : On heating slowly, salicylic acid forms phenol.



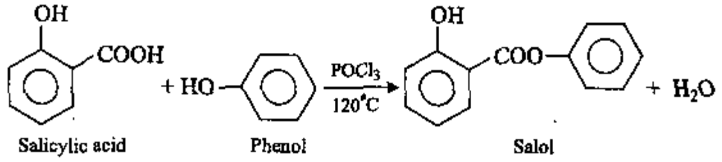
However, on heating salicylic acid at 200°C, phenyl salicylate *(salol)* is formed.



(iv) Action with soda lime : Phenol is formed.

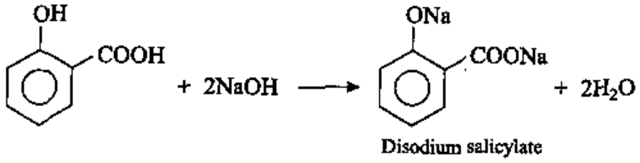


(v) Action with phenol : Salicylic acid reacts with phenol at 120°C in the presence of POCl$_3$ to give salol.

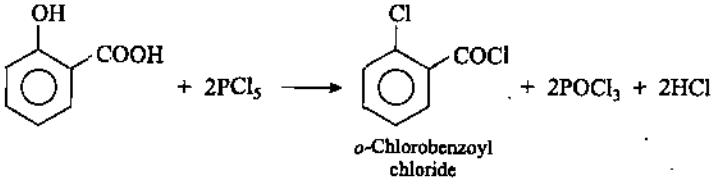


(3) Reactions Due to Both —OH and —COOH Groups

(i) Action with NaOH : Disodium salicylate is formed.

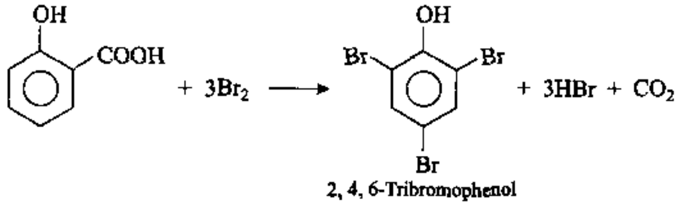


(ii) Action with PCl$_5$: *o*-Chlorobenzoyl chloride is formed.

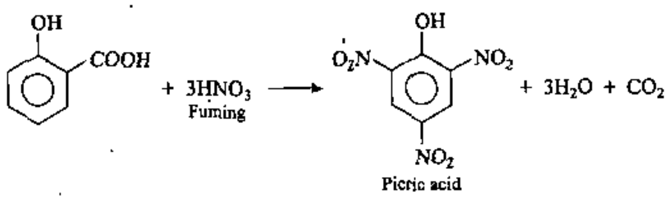


(4) Reactions Due to Benzene Nucleus

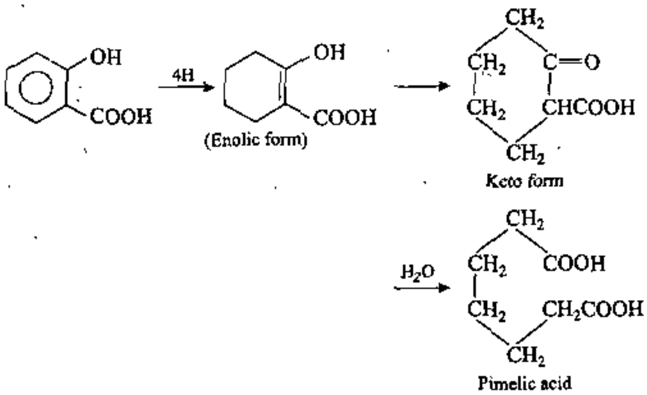
(i) Halogenation : Salicylic acid reacts with Bromine water to give a white precipitate of 2, 4, 6 tribromophenol.



(ii) Nitration : Salicylic acid reacts with fuming nitric acid to form 2, 4, 6 trinitrophenol *(picric acid).*



***(iii) Reduction* :** On Reducing salicylic acid with sodium and iso-pentyl alcohol, pimelic acid is formed.



The above comparison of properties show that salicylic acid combines the properties of phenol and benzoic acid.

[III] Uses

The most important use of salicylic acid is in the preparation of medicines, *e.g.*,

(i) As a germicide in skin diseases.
(ii) Aspirin is used as pain killer.
(iii) Salol is used in tooth pastes.
(iv) Sodium salicylate is used in gout diseases.
(v) Oil of winter green is used in medicines and in perfumes.
(vi) In the preparation of azo dyes.

[IV] Structure Of Salicylic Acid

(i) Molecular formula : The elementary analysis and molecular weight determination shows that the molecular formula of salicylic acid is $C_7H_6O_3$.

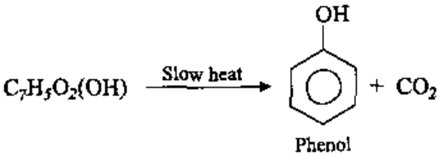
(ii) Presence of —OH group : This fact is indicated from the following reactions :

(a) The aqueous solution of salicylic acid reacts with 1% $FeCl_3$ solution to give violet solution.

(b) Salicylic acid reacts with acetic anhydride or acetyl chloride to form acetyl derivative.

$$C_7H_5O_2\,(OH) + CH_3COCl \longrightarrow \underset{\text{Acetyl salicylic acid}}{C_7H_5O_2(OCOCH_3)} + HCl$$

(c) Salicylic acid gives phenol on slow heating.



These reactions show that salicylic acid is a phenolic compound.

(iii) Presence of —COOH group : This fact is indicated from the following reactions :

(a) Salicylic acid reacts with sodium bicarbonate to give effervescence.

$$C_6H_4(OH)\,(COOH) + NaHCO_3 \longrightarrow \underset{\text{Sodium salicylate}}{C_6H_4\,(OH)\,(COONa)} + H_2O + CO_2\uparrow$$

(b) Salicylic acid reacts with alcohol in presence of conc. H_2SO_4 to form ester.

$$C_6H_4\,(OH)\,(COOH) + CH_3OH \xrightarrow[-H_2O]{\text{Conc. } H_2SO_4} \underset{\text{Methyl salicylate}}{C_6H_4\,(OH)\,(COOCH_3)}$$

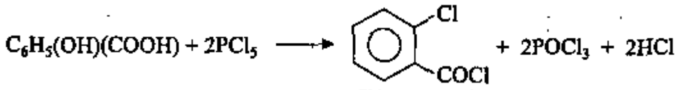
(c) Salicylic acid reacts with zinc dust to form benzoic acid.

$$C_6H_4\,(OH)\,(COOH) + Zn \longrightarrow \underset{\text{Benzoic acid}}{C_6H_5COOH} + ZnO$$

These reactions show that salicylic acid is a phenolic acid.

(iv) Relative position of —OH and —COOH groups :

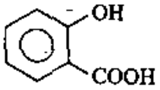
(a) Salicylic acid reacts with PCl_5 to form *o*-chloro benzoyl chloride.



o-Chloro benzoyl choride

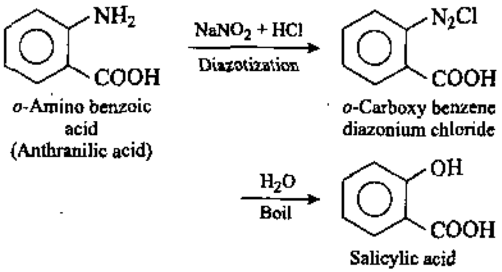
This shows that both —OH and —COOH groups are present in *o*-positions.

On the basis of the above facts, salicylic acid can be assigned the following structure :



Salicylic acid
(*o*-Hydroxy benzoic acid)

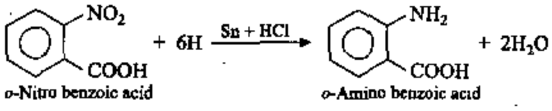
(v) Confirmation : The above structure of salicylic acid is confirmed by its synthesis from *o*-aminobenzoic acid.



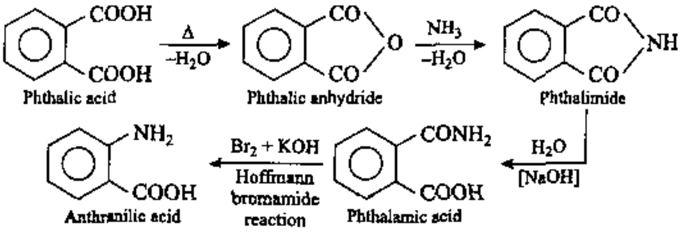
• 2.12. ANTHRANILIC ACID

[I] Preparation

(i) From o-nitro benzoic acid : Anthranilic acid is prepared by reducing *o*-nitrobenzoic acid with Sn and HCl.



(ii) From phthalic acid : Anthranilic acid can be prepared from phthalic acid in the following stages.



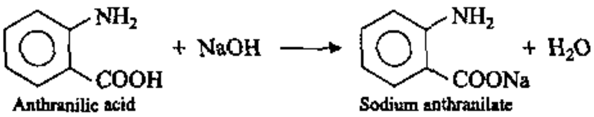
[II] Physical Properties

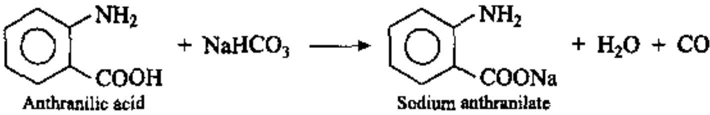
Anthranilic acid is a white solid, M. Pt. 145°C. It is soluble in water, alcohol and ether. It behaves as an acid and an amine.

[III] Chemical Properties

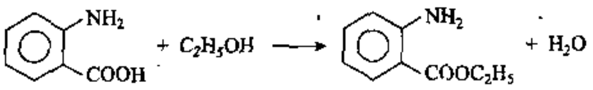
(1) Reaction Due to —COOH Group

(a) Salt formation : Anthranilic acid forms salts with alkalies like NaOH, $NaHCO_3$ etc.



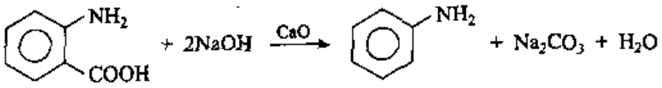


(b) Esterification : Anthranilic acid reacts with ethanol to form ethyl anthranilate (ester).



Ethyl anthranilate

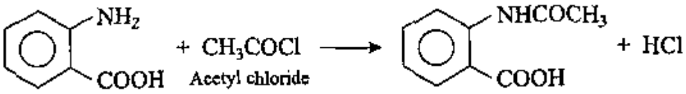
(c) Decarboxylation : On decarboxylation with NaOH, anthranilic acid forms *aniline*.



Aniline

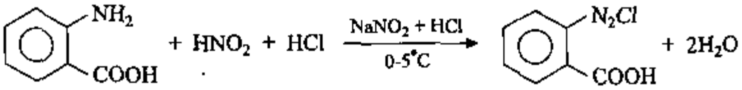
(2) Reactions Due to NH$_2$ Group :

(a) Acetylation : Anthramilic acid reacts with CH_3COCl to form acetyl anthranilic acid.



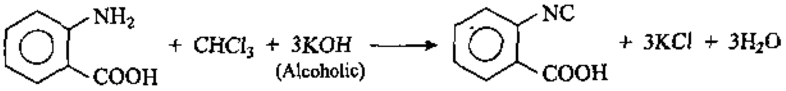
Anthranilic acid Acetyl chloride Acetyl anthranilic acid

(b) Diazotization :



o-Carboxy benzene diazonium chloride

(c) Carbylamine reaction : When anthranilic acid is treated with chloroform and alc. KOH, isocyanobenzoic acid is formed.



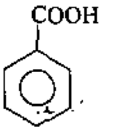
o-Isocyanobenzoic *acid*

[IV] Uses

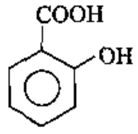
Anthranilic acid is used in the synthesis of dyes. Its ester methyl anthralinate is used in perfumery.

• SUMMARY

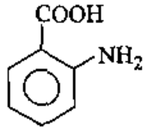
- Aromatic acids are compounds in which one or more carboxylic groups (–COOH) are attached directly to the aromatic ring, *e.g.*,



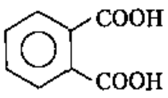
Benzoic acid



Salicylic acid

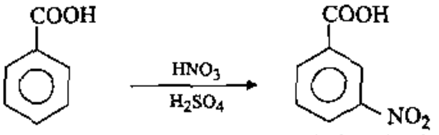


Anthranilic acid



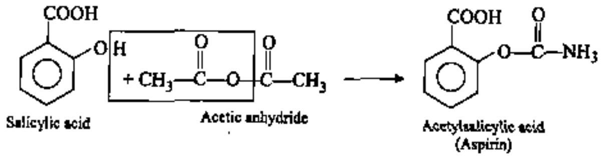
Phthalic acid

- The simplest aromatic carboxylic acid is benzoic acid.
- The benzene ring of benzoic acid undergoes the usual electrophilic substitution reactions. The –COOH group is a *meta* director and deactivating, *e.g.*,

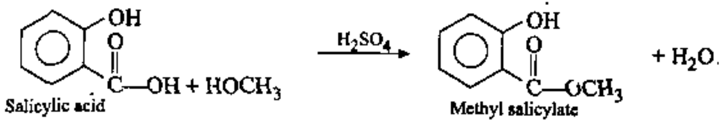


Benzoic acid *m*-Nitrobenzoic acid

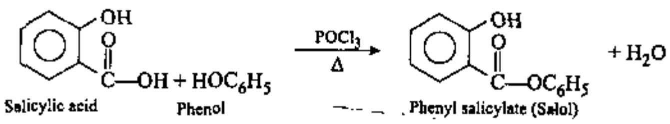
- Carboxylic acids undergo esterification when treated with an alcohol.
- Tartaric acid is a dihydroxy succinic acid.
- Mixture of *alkaline H_2O_2 and $FeSO_4$ is known as Fenton's reagent.*
- Citric acid has three carboxylic groups and one hydroxyl group.
- Aspirin is acetylsalicylic acid and is obtained by heating salicylic acid with acetyl chloride or acetic anhydride in the presence of phosphoric acid. It is a pain killer.



- Oil of winter green or methyl salicylate is prepared by esterifying salicylic acid with methanol in the presence of H_2SO_4.



- Methyl salicylate is a pleasant smelling liquid and is used in hair tonics and ointments for treating aches, sprains and bruises.
- Salol (phenyl salicylate) is obtained by heating salicylic acid with phenol in the presence of $POCl_3$.



- Salol is a colourless solid and is used as an antiseptic.
- Anthranilic acid is the *ortho* isomer of aminobenzoic acid.
- Anthranilic acid is a colourless solid and is used in the synthesis of dyes.

• STUDENT ACTIVITY

1. Discuss the acidity of carboxylic acids.

2. How will you synthesise benzamide from benzoic acid ?

3. How is salicylic acid prepared from phenol ?

4. Write two important properties of benzoic acid with reactions.

5. Explain why nitration of benzoic acid gives *m*-nitrobenzoic acid ?

6. How will you distinguish between phenol and salicylic acid ?

7. What happens when benzoic acid is heated with soda lime ?

8. How will you prepare benzyl alcohol from benzoic acid ?

9. Write the preparation of anthranilic acid ?

10. How is oil of writer green and salol prepared from salicylic acid ? Give reactions also.

• TEST YOURSELF

Answer the following questions :

1. Describe the general methods of preparation of carboxylic acids.
2. Describe the general properties of carboxylic acids.
3. Describe the mechanism of esterification of carboxylic acids.
4. Write a short note on Hell-Volhard-Zelinsky reaction.
5. Describe the acidity of carboxylic acids.
6. Mention of effect of substituents on acidity and give the relative acidity for carboxylic acids.
7. Explain why trichloroacetic acid is a stronger acid than acetic acid ?
8. Arrange the following compounds in the increasing order of their acid strength : $ClCH_2COOH$, $BrCH_2COOH$, $CNCH_2COOH$. CH_3COOH and $CH_3CH_2CH_2COOH$.
9. How is tartaric acid prepared ?
10. Mention the properties and uses of tartaric acid.
11. How will you show that tartaric acid is a dihydroxy succinic acid ?
12. What happens when ?
    (i) Tartaric acid is treated with Tollen's reagent.
    (ii) Tartaric acid is treated with Fenton's reagent.
    (iii) Tartaric acid is heated alone.
13. What is Fenton's reagent ?
14. How is citric acid prepared ?
15. Give the important properties and uses of citric acid.
16. What is the action of heat on citric acid ?
17. Write the preparation of aconitic acid from citric acid ?
18. Show that citric acid behaves as an α-hydroxy acid as well as β-hydroxy acid.

19. How will you show that tartaric acid contains two carboxylic and two hydroxyl groups ?

20. Show that citric acid contains three carboxylic and one hydroxyl group.

21. What is the action of heat on α, β and γ-hydroxy acids ?

22. Describe the distinction between tartaric acid and citric acid.

23. What are aromatic carboxylic acids ?

24. Describe the preparation of benzoic acid.

25. Mention the important properties of benzoic acid.

26. Starting from benzoic acid, how will you prepare the following compounds ?
(i) Benzamide (ii) Benzene (iii) Benzoic anhydride
(iv) Benzophenone (v) Acetophenone (vi) Aniline
(viii) Phenyl acetic acid (viii) Ethyl benzoate

27. Explain why *p*-nitrobenzoic acid is stronger than benzoic acid ?

28. How is salicylic acid prepared ?

29. Describe the properties and uses of salicylic acid.

30. Describe the preparation of methyl salicylate.

31. Show how salicylic acid combines the properties of phenol and benzoic acid ?

32. How will you obtain the following compounds from salicylic acid ?
(i) Aspirin (ii) Salol (iii) Phenol (iv) Benzoic acid
(v) Oil of winter green

33. Describe the preparation of anthranilic acid.

34. Describe the properties of anthranilic acid.

35. How will you distinguish between cinnamic acid and benzoic acid ?

36. How will you distinguish between salicylic acid and benzoic acid ?

37. How will you distinguish between salicylic acid and phenol ?

38. Starting from benzoic acid, how will you obtain the following compounds ?
(i) Phenol (ii) Benzonitrile (iii) Benzyl alcohol

39. Discuss the structure of citric acid.

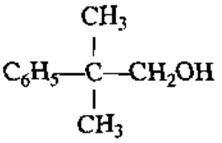
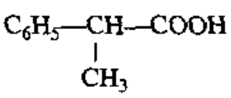
40. Discuss the structure of salicylic acid.

41. Which of the following compound is most acidic ?
(i) $CH_3—CH_2—COOH$ (ii) $Br—CH_2—CH_2—COOH$
(iii) $CH_3—CH(Br)—COOH$ (iv) $CH_3—CH(F)—COOH$

42. Which of the following is the strongest acid in aqueous solution ?
(i) CH_3COOH (ii) $ClCH_2COOH$ (iii) CH_3CH_2COOH (iv) $Cl_2CHCOOH$

43. Which of the following compound on treatment with $NaHCO_3$ will give CO_2 ?
(i) Ethylamine (ii) Acetone (iii) Methanol (iv) Acetic acid

44. Which of the following compound will not give benzoic acid with $KMnO_3/OH$?

(i) $C_6H_5CH(CH_3)_2$ (ii) $C_6H_5CH_2OH$ (iii) 
$C_6H_5—\underset{CH_3}{\overset{CH_3}{\underset{|}{\overset{|}{C}}}}—CH_2OH$
(iv) 
$C_6H_5—\underset{CH_3}{\underset{|}{CH}}—COOH$

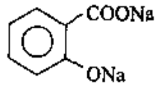
45. Acid can be reduced with :
(i) CH_3Li (ii) $LiAlH_4$ (iii) Al/P (iv) All of these

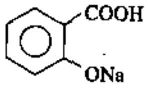
46. In the given reaction, $CH_3CH_2COOH \xrightarrow[Br_2/\Delta]{Ag_2O} [X]$

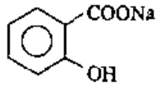
[X] will be :
(i) Ethyl bromide (ii) Propyl bromide (iii) Propyl propanoate (iv) Ethyl propanoate

47. Which one of the following compounds will give HVZ reaction ?
(i) 2-Methyl propanoic acid (ii) Benzoic acid
(iii) Formic acid (iv) 2, 2-Dimethylpropanoic acid

48. Salicyclic acid reacts with sodium bicarbonate to form :

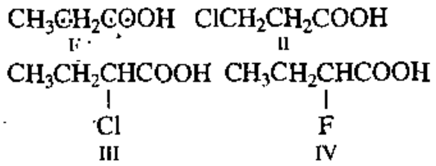
(a) 

(b) 

(c) 

(d) C_6H_5ONa

49. Using the given code, arrange the following carboxylic acids in decreasing order of acidity :



CH_3CH_2COOH (I) $ClCH_2CH_2COOH$ (II)

$\underset{Cl}{CH_3CH_2\underset{|}{C}HCOOH}$ (III) $\underset{F}{CH_3CH_2\underset{|}{C}HCOOH}$ (IV)

(i) II > I > III > IV (ii) IV > III > II > I

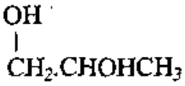
(iii) III > IV > II > I (iv) IV > II > III > I

50. Predict the product(s) of the reaction :

$$CH_3COCOOH \xrightarrow[\text{(ii) } H_3O^+]{\text{(i) } LiAlH_4/THF} \ldots\ldots\ldots$$

(i) $CH_3CHOHCH_2OH$

(ii)



$\overset{OH}{\overset{|}{C}H_2}.CHOHCH_3$

(iii) $CH_2FCHOHCH_2OH$ (iv) $CH_3CH_2CH_2OH$

51. Fill in the blanks :

(i) When tartaric acid is oxidised with nitric acid, ... is formed.

(ii) *Cyclohexanone when oxidised by HNO_3 gives ....*

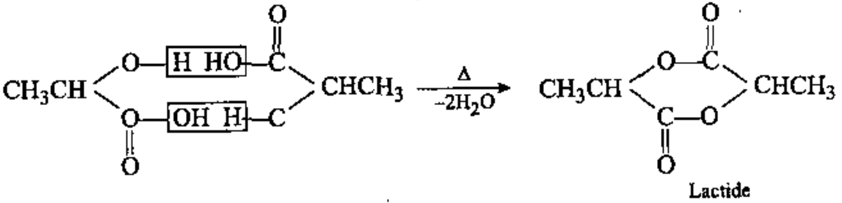
(iii) The characteristic reaction of carboxylic acid is .... substitution.

(iv) Carboxylic acid are .... acidic than alcohols.

(v) The product (A) in the reaction, propionic acid + $SOCl_2 \rightarrow$ (A), is ....

ANSWERS

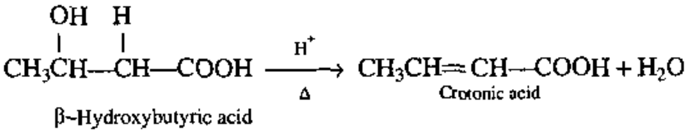
21. **α-Hydroxy acids** form an intermolecular cyclic diester called a lactide. They do so by reaction between OH of one molecule with COOH group of the second molecule.



Lactide

Lactides when boiled with water give back α-hydroxy acid.

β-Hydroxy acids dehydrate by splitting out OH and H from adjacent carbon atoms, forming unsaturated acids.

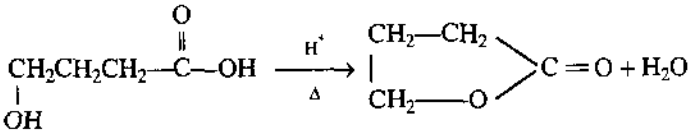


$$CH_3\overset{OH}{\overset{|}{C}H}-\overset{H}{\overset{|}{C}H}-COOH \xrightarrow[\Delta]{H^+} \underset{\text{Crotonic acid}}{CH_3CH=CH-COOH} + H_2O$$

β-Hydroxybutyric acid

$$\underset{\text{Hydracrylic acid}}{HOCH_2CH_2COOH} \xrightarrow{\Delta} \underset{\text{Acrylic acid}}{CH_2=CHCOOH} + H_2O$$

γ-Hydroxy acids form internal esters known as lactones. The COOH at one end of the *molecule reacts with OH on the other to form 5-membered cyclic ester, i.e.,* γ-lactones.

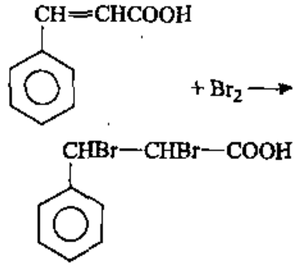
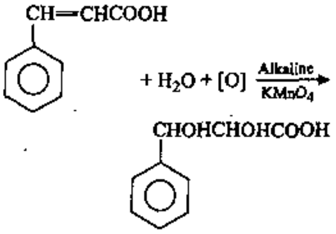
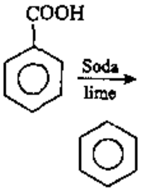
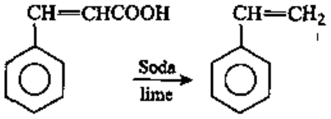


γ-Hydroxybutyric acid γ-Lactone

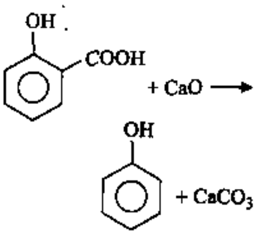
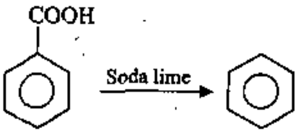
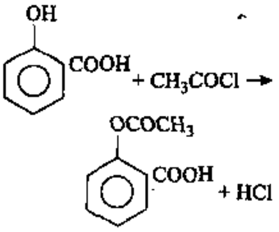
22.

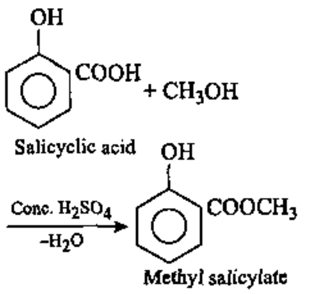
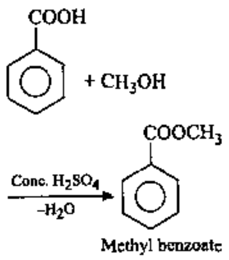
	Property	Tartaric acid	Citric acid
1.	M. Pt.	171°	100°
2.	Optical rotation	Exhibits optical activity	Does not exhibit optical activity
3.	Action of HI	Forms succinic acid	Forms tricarballylic acid
4.	Action of conc. H_2SO_4	Forms CO, CO_2, SO_2, H_2O	Forms CO, H_2O and acetone dicarboxylic acid
5.	Treatment with Tollen's reagent (*ammonical silver nitrate solution*)	Silver mirror is formed	Does not give silver mirror.

35.

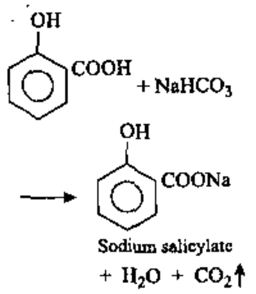
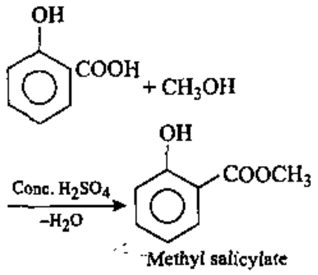
Property	Benzoic acid	Cinnamic acid
1. Melting point	122°C	133°C
2. Action with Br_2.	No reaction.	It decolourizes the colour of Br_2 water.  Dibromocinnamic acid
3. Action with alkaline $KMnO_4$.	No reaction.	It decolourizes the colour of alkaline $KMnO_4$.  β-Phenyl glyceric acid
4. Action with soda lime.	Benzene is formed.  	Styrene is formed.  Styrene

36.

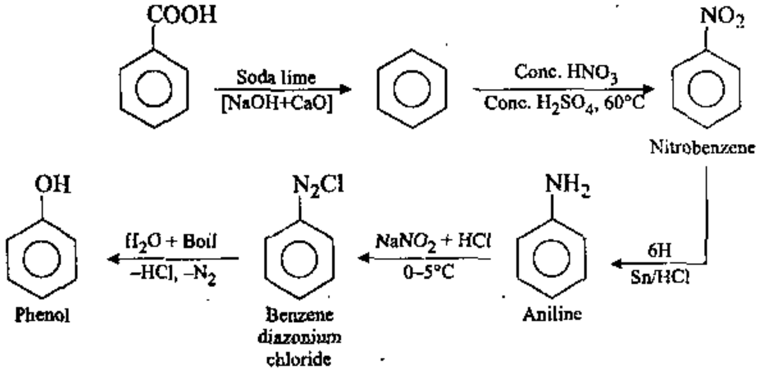
Property	Salicylic acid	Benzoic acid
1. M. Pt.	156°C	122°C
2. Action of $FeCl_3$ solution.	Gives violet colour.	Neutral solution gives buff precipitate.
3. Action with soda lime.	Phenol is formed.  Phenol	Benzene is formed. 
4. Action with CH_3COCl	Acetyl salicylic acid (*aspirin*) is formed.  Acetyl salicylic acid	No reaction.

5. Action with CH_3OH and few drops of conc. H_2SO_4	Methyl salicylate is obtained which has smell of oil of winter green. 	Methyl benzoate is obtained which has no such smell. 

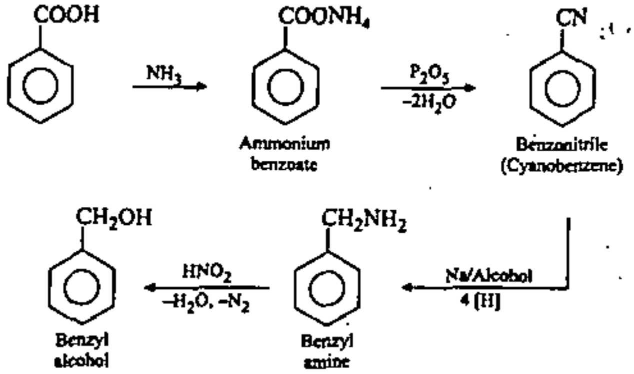
37.

Property	Salicylic acid	Phenol
1. Physical state	Colourless crystalline solid.	Colourless solid when pure but turns pink in air and light due to oxidation.
2. Melting point	156°C	42°C
3. Smell	—	Characteristic phenolic smell
4. Hot aq. solution + solid $NaHCO_3$	Gives effervescence 	No reaction.
5. Action of CH_3OH and few drops of conc. H_2SO_4	Methyl salicylate is obtained which has a smell of oil of winter green. 	No reaction.

38. (i) Phenol form benzoic acid.



(ii) Benzonitrile and benzyl alcohol from benzoic acid.



41. (iv) **42.** (iv) **43.** (iv) **44.** (iii) **45.** (iv) **46.** (i)

47. (iii) **48.** (ii) **49.** (i) **50.** (iv)

51. (i) oxalic acid (ii) adipic acid (iii) nucleophilic
(iv) more (v) CH_3CH_2COCl

❑❑❑

UNIT

3

ORGANOMETALLIC COMPOUNDS AND AROMATIC SULPHONIC COMPOUNDS

STRUCTURE

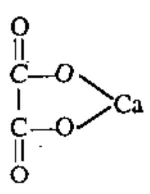
• 3.1. ORGANO METALLIC COMPOUNDS

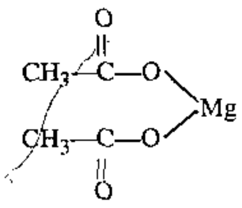
Organic compounds in which a metal atom is directly linked to carbon are generally known as ***organometallic compounds.*** The term metal generally includes elements less electronegative than carbon. Thus, the definition also includes the derivatives of non-metals such as boron, silicon and derivatives of metalloids such as germanium, arsenic and antimony. In other words, *organometallic compounds are those in which an organic group is attached through carbon to an atom which is less electronegative than carbon.*

C_2H_5MgBr Ethyl magnesium bromide	$C_2H_5—Zn—C_2H_5$ Diethylzinc

$C_2H_5—Li$ *Ethyllithium*	$(C_2H_5)_4Pb$ *Tetraethyl lead*	$(C_2H_5)_2Hg$ *Diethylmercury*	$(CH_3)_3As$ *Trimethylarsenic*

Compounds like calcium oxalate (CaC_2O_4) and magnesium acetate $Mg(CH_3COO)_2$ are not organometallic compounds as the metal is directly attached to oxygen atom and not to carbon atom.





Magnesium acetate

• 3.2. GRIGNARD'S REAGENTS

The organometallic compounds of magnesium are known as **Grignard's reagents**. Victor Grignard, a French chemist in 1900 discovered that magnesium metal reacts with alkyl halides in presence of dry *ether and form alkyl magnesium halides* (R—Mg—X) which remain dissolved in ether. They were later on named as Grignard's reagents after the name of its discoverer Grignard. The Grignard reagents have the general formula R—Mg—X, where, R = alkyl (CH_3, C_2H_5, C_3H_7 etc.) or aryl (C_6H_5) radical and X = Cl, Br or I, *e.g.*,

$CH_3—MgI$ Methyl magnesium iodide

$C_2H_5—MgBr$ Ethyl magnesium bromide

[I] Method of Preparation

The Grignard reagents are prepared by the action of alkyl halides on magnesium in presence of dry ether.

$$R—X + Mg \xrightarrow[\text{Ether}]{\text{Reflux}} R—Mg—X$$

$$CH_3I + Mg \xrightarrow{\text{Reflux}} \underset{\text{Methyl magnesium iodide}}{CH_3MgI}$$

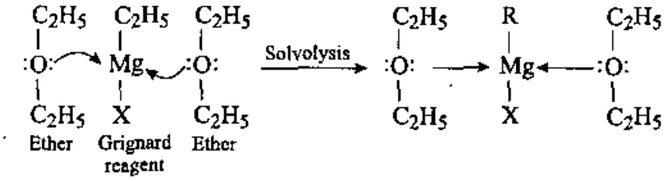
$$C_2H_5Br + Mg \xrightarrow{\text{Reflux}} \underset{\text{Ethyl magnesium bromide}}{C_2H_5MgBr}$$

Alkyl iodides are more reactive than bromides, which are in turn more reactive than chlorides. Alkyl bromides are most suitable for the preparation of Grignard reagents.

In practice, a Grignard reagent is produced by dropping a solution of the alkyl halide in dry ether into the reaction flask containing magnesium ribbon suspended in dry ether. The ether solution of the Grignard reagent thus obtained is used immediately in the flask in which it is prepared. Diethyl ether plays two important roles.

(i) It provides a medium for the reaction, and

(ii) It dissolves the Grignard reagents through solvolysis (reaction with solvent).



[II] Precautions

Before the preparation of Grignard reagents the following precautions are taken.

(1) There should be no naked flames anywhere in the vicinity, because diethyl ether is inflammable and catches fire at once.

(2) The apparatus used for the preparation of the Grignard reagents must be completely dry and pure, because the slightest traces of moisture will side track the main reaction.

(3) All the reagents used should be absolutely pure and dry. The reagents are purified and dried as follows :

(i) *Magnesium* : Magnesium ribbon is rubbed with sand paper to remove the film of oxide and is then cut into small pieces. It is then washed with dry ether to remove grease and then dried in an oven at 120°C.

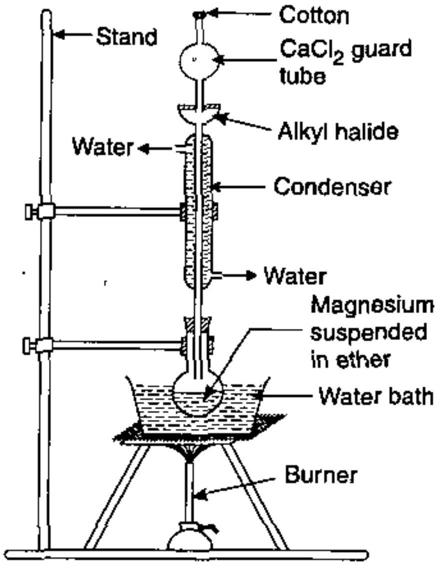


Fig. 1. Preparation of Grignard's reagent.

(ii) *Ether* : Ether is washed with water to remove any alcohol and then dried over anhydrous calcium chloride for 2-3 days to remove traces of alcohol and moisture. It is then distilled over sodium and phosphorus penta-oxide to remove final traces of alcohol and water.

(iii) *Alkyl halide* : Alkyl halide is dried over anhydrous $CaCl_2$ and then distilled over P_2O_5.

[III] Procedure

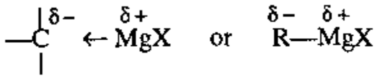
The apparatus in the preparation of Grignard's reagent is shown in figure (1). Pure and dry magnesium ribbon is cut into small pieces and suspended in pure and dry ether contained in round bottom flask. It is connected to a reflux condenser carrying a $CaCl_2$ tube at the other end. A crystal of iodine (catalyst) is added in the flask. It helps to start the reaction, but once the reaction starts it is very vigorous and the flask is to be cooled. Alkyl halide is added from above after removing $CaCl_2$ tube for a moment. When the reaction is complete, a clear solution of the Grignard's reagent in dry ether is obtained. This is then treated with various reagents to get the desired *synthetic products*.

[IV] Physical Properties

Grignard's reagents are non-volatile, colourless solids. They are never isolated in the free state on account of their explosive nature. Therefore, for synthetic purposes, the Grignard reagents are always prepared and used in ethereal solution.

[V] Chemical Properties

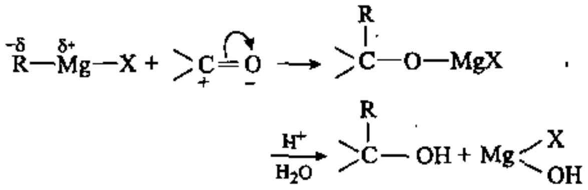
The C–Mg bond in Grignard reagents is covalent but highly polar. The carbon atom is more electronegative than magnesium. The electrons of the C–Mg bond are drawn towards the carbon atom. As a result, the carbon atom has a partial negative charge and the magnesium atom has a partial positive charge.



$$-\overset{|}{\underset{|}{\overset{\delta-}{C}}} \leftarrow \overset{\delta+}{MgX} \quad \text{or} \quad \overset{\delta-}{R}{-}\overset{\delta+}{MgX}$$

The alkyl groups in Grignard reagents being electron rich can act as carbanions or nucleophiles. They would attack polarised molecules at points of low electron density. Thus, the characteristic reactions of Grignard reagents are (1) nucleophilic substitution or double decomposition (2) nucleophilic addition reactions.

The Grignard reagents undergo substitution reactions by the following general mechanism.

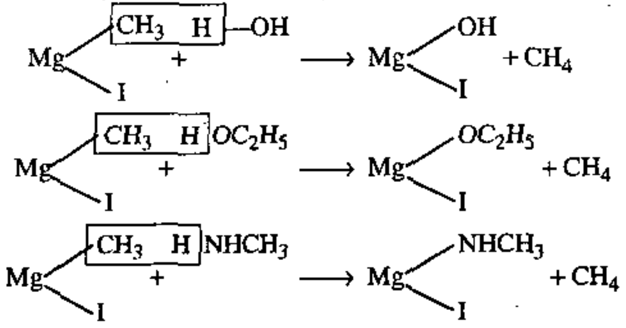


$$\overset{-\delta}{R}{-}\overset{\delta+}{Mg}{-}X + >\overset{}{\underset{+}{C}}{=}\underset{-}{O} \longrightarrow >\overset{R}{\overset{|}{C}}{-}O{-}MgX$$

$$\xrightarrow[H_2O]{H^+} >\overset{R}{\overset{|}{C}}{-}OH + Mg<^{X}_{OH}$$

[VI] Synthetic Importance

(1) Formation of alkanes : Grignard reagent reacts with compounds containing active hydrogen atom, *i.e.*, with water, alcohol, amines etc. to form alkanes.



$$Mg<^{\boxed{CH_3\ \ H}-OH}_{I} \longrightarrow Mg<^{OH}_{I} + CH_4$$

$$Mg<^{\boxed{CH_3\ \ H}OC_2H_5}_{I} \longrightarrow Mg<^{OC_2H_5}_{I} + CH_4$$

$$Mg<^{\boxed{CH_3\ \ H}NHCH_3}_{I} \longrightarrow Mg<^{NHCH_3}_{I} + CH_4$$

(2) Formation of alkenes : Grignard reagent forms alkenes with unsaturated halide.

$$CH_3\boxed{MgI + I}\underset{\text{Vinyl iodide}}{-CH{=}CH_2} \longrightarrow \underset{\text{Propene}}{CH_3{-}CH{=}CH_2} + MgI_2$$

$$CH_3\boxed{MgI + I}\underset{\text{Allyl iodide}}{-CH_2{-}CH{=}CH_2} \longrightarrow \underset{\text{Butene-1}}{CH_3{-}CH_2{-}CH{=}CH_2} + MgI_2$$

(3) Formation of alkyl halides : Grignard reagent reacts with iodine to form alkyl iodide.

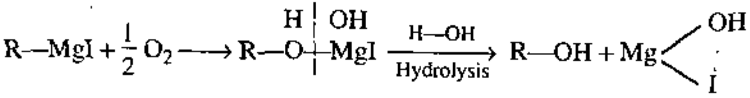
$$R{-}MgI + I_2 \longrightarrow R{-}I + MgI_2$$

$$C_2H_5MgI + I_2 \longrightarrow \underset{\text{Ethyl iodide}}{C_2H_5{-}I} + MgI_2$$

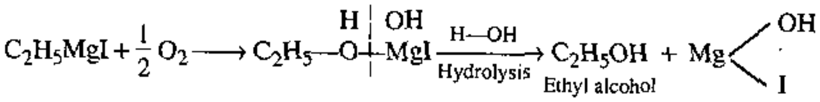
(4) Formation of alcohols : All the three types of alcohols can be prepared by Grignard reagents.

(a) Primary alcohols : Grignard reagent reacts with dry O_2, HCHO or ethylene oxide to give a compound which on hydrolysis gives primary alcohol.

(i) From oxygen :

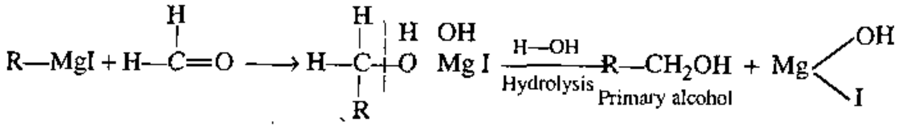


$$R{-}MgI + \frac{1}{2}O_2 \longrightarrow R{-}\overset{H}{O}{-}\overset{OH}{MgI} \xrightarrow[\text{Hydrolysis}]{H{-}OH} R{-}OH + Mg\begin{array}{l}OH\\ I\end{array}$$

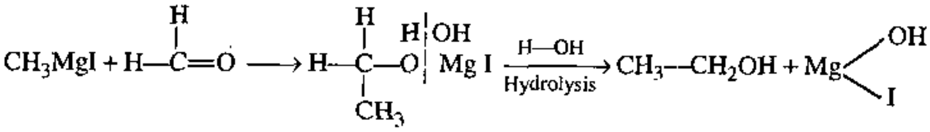


$$C_2H_5MgI + \frac{1}{2}O_2 \longrightarrow C_2H_5{-}\overset{H}{O}{-}\overset{OH}{MgI} \xrightarrow[\text{Hydrolysis}]{H{-}OH} \underset{\text{Ethyl alcohol}}{C_2H_5OH} + Mg\begin{array}{l}OH\\ I\end{array}$$

(ii) From formaldehyde :

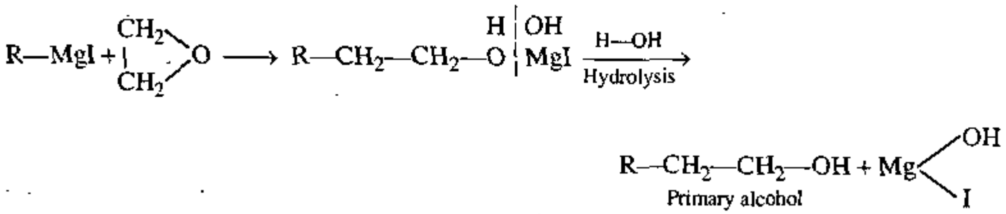


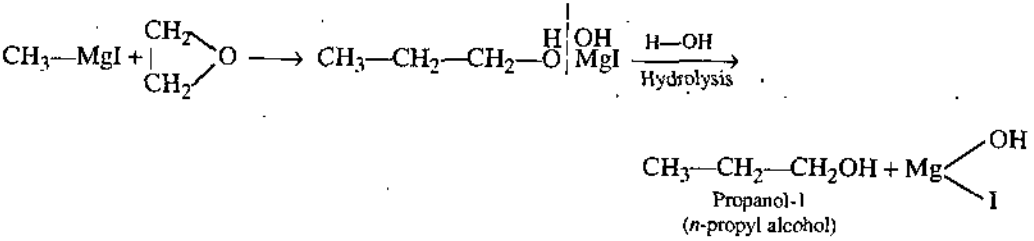
$$R{-}MgI + H{-}\overset{H}{C}{=}O \longrightarrow H{-}\underset{R}{\overset{H}{C}}{-}\overset{H}{O}\ \overset{OH}{MgI} \xrightarrow[\text{Hydrolysis}]{H{-}OH} \underset{\text{Primary alcohol}}{R{-}CH_2OH} + Mg\begin{array}{l}OH\\ I\end{array}$$



$$CH_3MgI + H{-}\overset{H}{C}{=}O \longrightarrow H{-}\underset{CH_3}{\overset{H}{C}}{-}\overset{H}{O}\ \overset{OH}{MgI} \xrightarrow[\text{Hydrolysis}]{H{-}OH} CH_3{-}CH_2OH + Mg\begin{array}{l}OH\\ I\end{array}$$

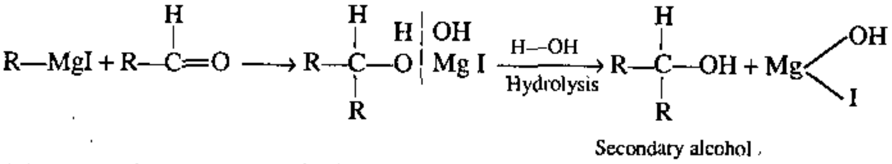
(iii) From ethylene oxide :





(b) Secondary alcohols : Grignard reagent reacts with aldehydes other than formaldehyde or ethyl formate to give a compound which on hydrolysis gives secondary alcohol.

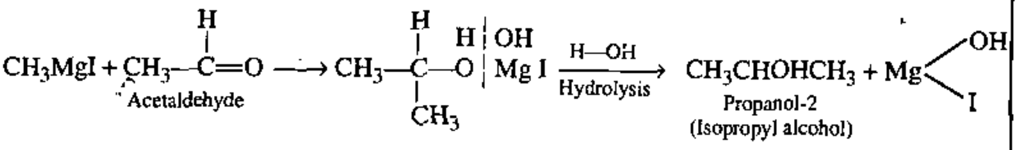
(i) From aldehydes other than formaldehyde :



$$R{-}MgI + R{-}\overset{H}{C}{=}O \longrightarrow R{-}\underset{R}{\overset{H}{C}}{-}\overset{H}{O}\ \overset{OH}{MgI} \xrightarrow[\text{Hydrolysis}]{H{-}OH} R{-}\underset{R}{\overset{H}{C}}{-}OH + Mg\begin{array}{l}OH\\ I\end{array}$$

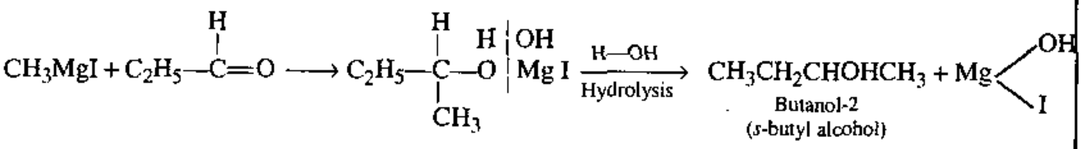
Secondary alcohol

(a) Propanol-2 (Isopropyl alcohol)



$$CH_3MgI + \underset{\text{Acetaldehyde}}{CH_3{-}\overset{H}{C}{=}O} \longrightarrow CH_3{-}\underset{CH_3}{\overset{H}{C}}{-}\overset{H}{O}\ \overset{OH}{MgI} \xrightarrow[\text{Hydrolysis}]{H{-}OH} \underset{\substack{\text{Propanol-2}\\ \text{(Isopropyl alcohol)}}}{CH_3CHOHCH_3} + Mg\begin{array}{l}OH\\ I\end{array}$$

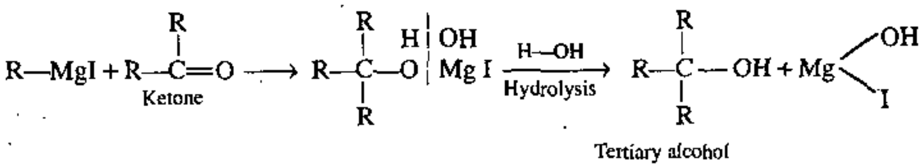
(b) Butanol-2 (s-butyl alcohol)

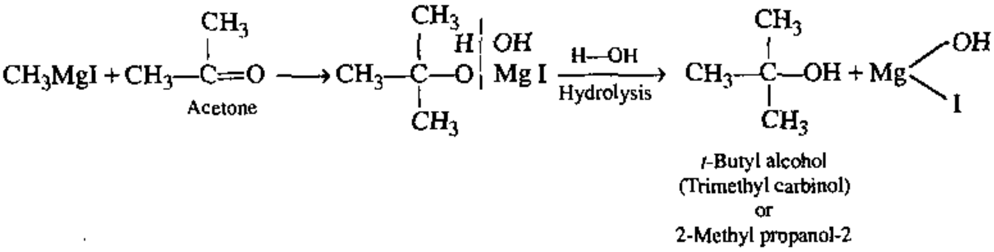


$$CH_3MgI + C_2H_5{-}\overset{H}{C}{=}O \longrightarrow C_2H_5{-}\underset{CH_3}{\overset{H}{C}}{-}\overset{H}{O}\ \overset{OH}{MgI} \xrightarrow[\text{Hydrolysis}]{H{-}OH} \underset{\substack{\text{Butanol-2}\\ \text{(s-butyl alcohol)}}}{CH_3CH_2CHOHCH_3} + Mg\begin{array}{l}OH\\ I\end{array}$$

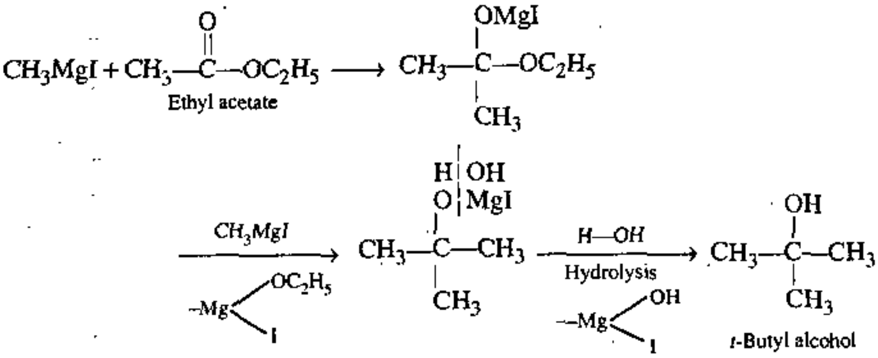
(c) Tertiary alcohols : Grignard reagent reacts with ketone, esters other than formic ester or acid chloride to give a product which on hydrolysis gives tertiary alcohol.

(i) From ketone :

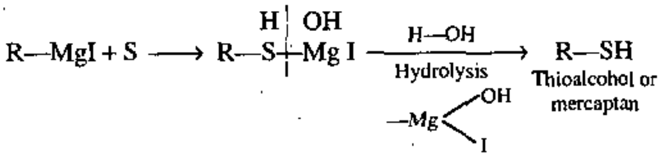


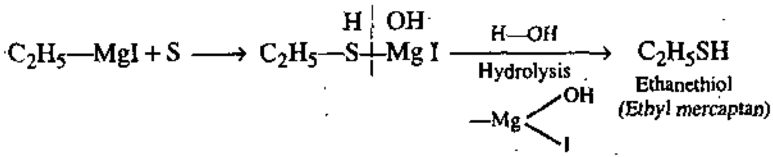


(ii) From esters other than formic ester :



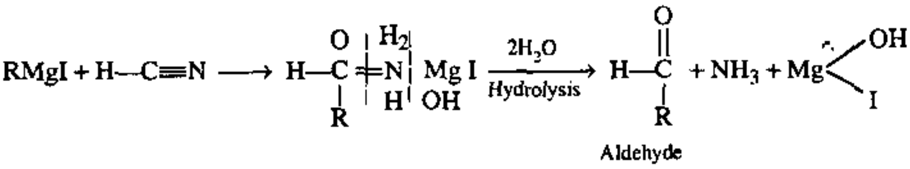
(5) Formation of thioalcohols : Grignard reagent reacts with sulphur and the product formed on hydrolysis gives thioalcohol (mercaptan).

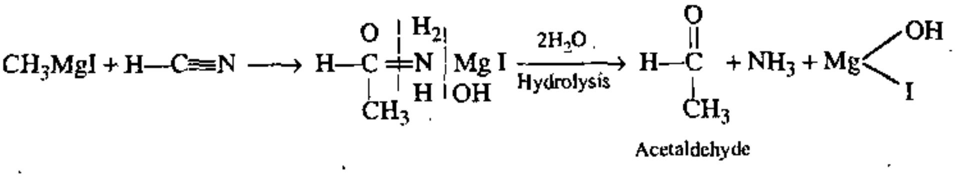




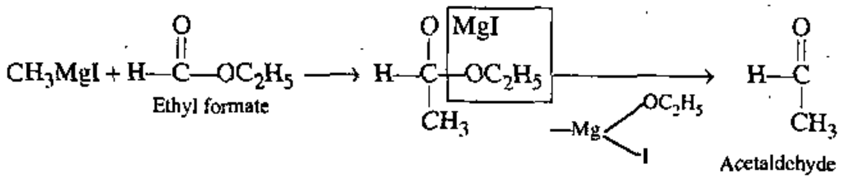
(6) Formation of aldehydes : Grignard reagent reacts with hydrogen cyanide, ethyl formate or ethyl ortho formate to give a product which on hydrolysis gives aldehyde.

(i) From hydrogen cyanide :





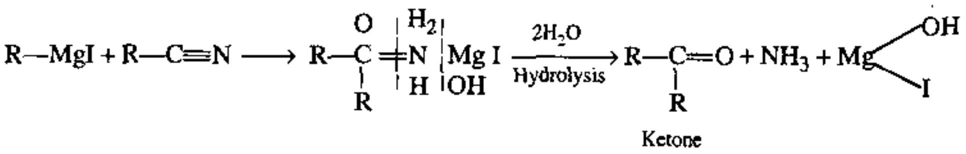
(ii) From ethyl formate :



$$CH_3MgI + \underset{\text{Ethyl formate}}{H-\overset{\overset{O}{\|}}{C}-OC_2H_5} \longrightarrow H-\underset{\underset{CH_3}{|}}{\overset{\overset{O\,\boxed{MgI}}{|}}{C}}\boxed{-OC_2H_5} \xrightarrow[-Mg{<}^{OC_2H_5}_{I}]{} \underset{\text{Acetaldehyde}}{H-\underset{\underset{CH_3}{|}}{\overset{\overset{O}{\|}}{C}}}$$

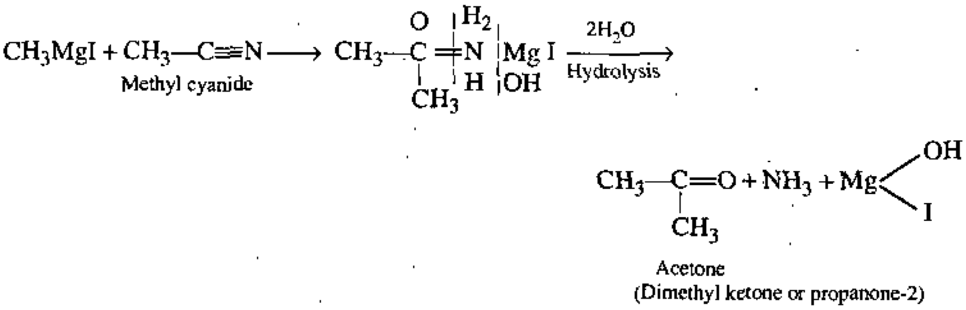
(7) Formation of ketones : Ketones are obtained by the reaction of Grignard reagent with alkyl cyanide, acid chloride, acetamide, acetic anhydride or ethyl acetate.

(i) From alkyl cyanide :



$$R-MgI + R-C\equiv N \longrightarrow R-\underset{\underset{R}{|}}{\overset{O}{C}}\overset{H_2}{\underset{H}{=N}}\,\underset{OH}{Mg\,I} \xrightarrow[\text{Hydrolysis}]{2H_2O} \underset{\text{Ketone}}{R-\underset{\underset{R}{|}}{C}=O} + NH_3 + Mg{<}^{OH}_{I}$$

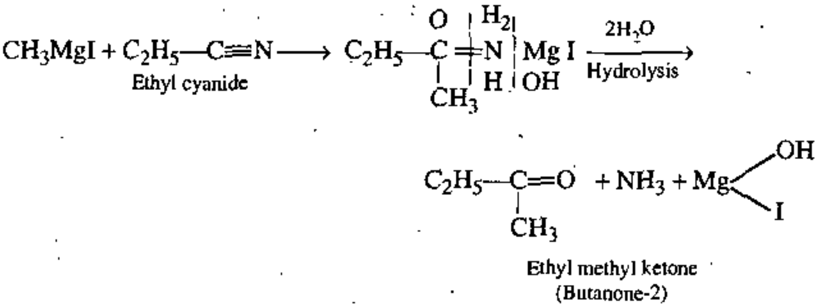
(a) Acetone :



$$CH_3MgI + \underset{\text{Methyl cyanide}}{CH_3-C\equiv N} \longrightarrow CH_3-\underset{\underset{CH_3}{|}}{\overset{O}{C}}\overset{H_2}{\underset{H}{=N}}\,\underset{OH}{Mg\,I} \xrightarrow[\text{Hydrolysis}]{2H_2O}$$

$$\underset{\substack{\text{Acetone}\\\text{(Dimethyl ketone or propanone-2)}}}{CH_3-\underset{\underset{CH_3}{|}}{C}=O} + NH_3 + Mg{<}^{OH}_{I}$$

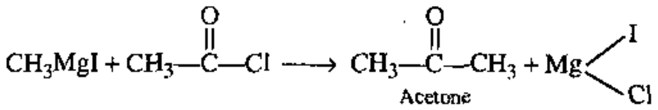
(b) Ethyl methyl ketone :



$$CH_3MgI + \underset{\text{Ethyl cyanide}}{C_2H_5-C\equiv N} \longrightarrow C_2H_5-\underset{\underset{CH_3}{|}}{\overset{O}{C}}\overset{H_2}{\underset{H}{=N}}\,\underset{OH}{Mg\,I} \xrightarrow[\text{Hydrolysis}]{2H_2O}$$

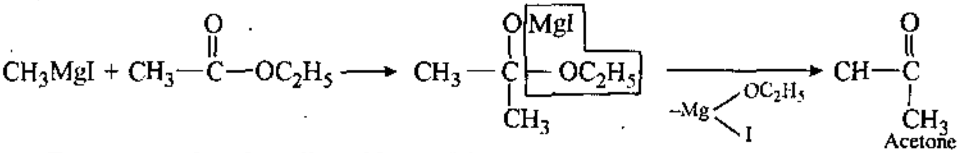
$$\underset{\substack{\text{Ethyl methyl ketone}\\\text{(Butanone-2)}}}{C_2H_5-\underset{\underset{CH_3}{|}}{C}=O} + NH_3 + Mg{<}^{OH}_{I}$$

(ii) From acid chloride :



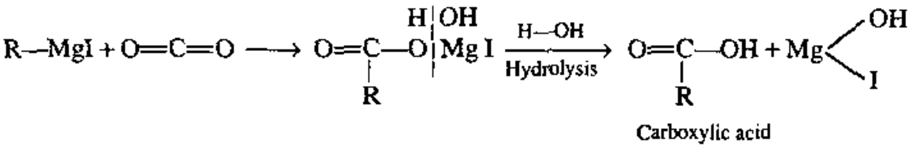
$$CH_3MgI + CH_3-\overset{\overset{O}{\|}}{C}-Cl \longrightarrow \underset{\text{Acetone}}{CH_3-\overset{\overset{O}{\|}}{C}-CH_3} + Mg{<}^{I}_{Cl}$$

(iii) From ethyl acetate :



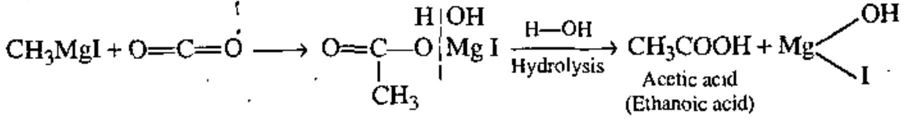
$$CH_3MgI + CH_3-\overset{\overset{O}{\|}}{C}-OC_2H_5 \longrightarrow CH_3-\underset{\underset{CH_3}{|}}{\overset{\overset{O\,\boxed{MgI}}{|}}{C}}\boxed{-OC_2H_5} \xrightarrow[-Mg{<}^{OC_2H_5}_{I}]{} \underset{\text{Acetone}}{CH-\underset{\underset{CH_3}{|}}{\overset{\overset{O}{\|}}{C}}}$$

(8) Formation of carboxylic acids : Grignard reagent reacts with solid CO_2 (dry ice) to give a product which on hydrolysis gives carboxylic acid.



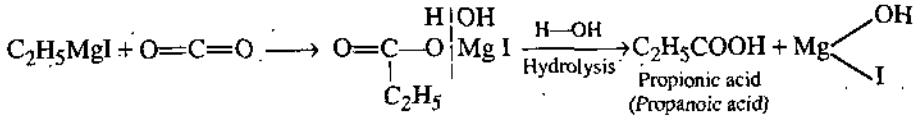
$$R-MgI + O=C=O \longrightarrow O=\underset{\underset{R}{|}}{C}-\overset{H}{O}\,\overset{OH}{Mg\,I} \xrightarrow[\text{Hydrolysis}]{H-OH} \underset{\text{Carboxylic acid}}{O=\underset{\underset{R}{|}}{C}-OH} + Mg{<}^{OH}_{I}$$

(a) Acetic acid :



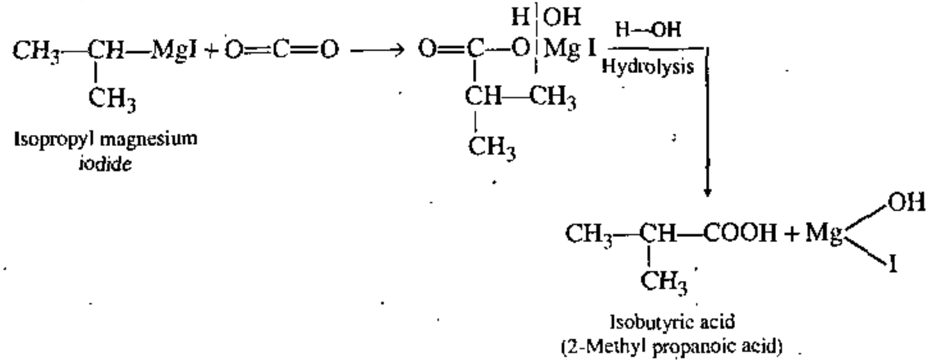
$$CH_3MgI + O{=}C{=}O \longrightarrow O{=}\underset{CH_3}{C}{-}O\,|\,MgI \xrightarrow[\text{Hydrolysis}]{H{-}OH} \underset{\substack{\text{Acetic acid}\\\text{(Ethanoic acid)}}}{CH_3COOH} + Mg\begin{smallmatrix}OH\\I\end{smallmatrix}$$

(b) Propionic acid :



$$C_2H_5MgI + O{=}C{=}O \longrightarrow O{=}\underset{C_2H_5}{C}{-}O\,|\,MgI \xrightarrow[\text{Hydrolysis}]{H{-}OH} \underset{\substack{\text{Propionic acid}\\\text{(Propanoic acid)}}}{C_2H_5COOH} + Mg\begin{smallmatrix}OH\\I\end{smallmatrix}$$

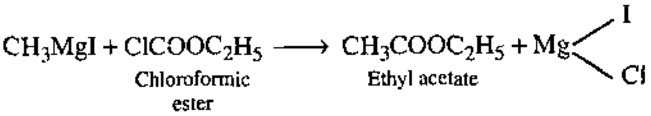
(c) Isobutyric acid :



$$\underset{\text{Isopropyl magnesium iodide}}{CH_3{-}\underset{CH_3}{CH}{-}MgI} + O{=}C{=}O \longrightarrow O{=}\underset{CH{-}CH_3\atop CH_3}{C}{-}O\,|\,MgI \xrightarrow[\text{Hydrolysis}]{H{-}OH} \underset{\substack{\text{Isobutyric acid}\\\text{(2-Methyl propanoic acid)}}}{CH_3{-}\underset{CH_3}{CH}{-}COOH} + Mg\begin{smallmatrix}OH\\I\end{smallmatrix}$$

(9) Formation of esters : Grignard reagent reacts with chloroformic ester to form ester.

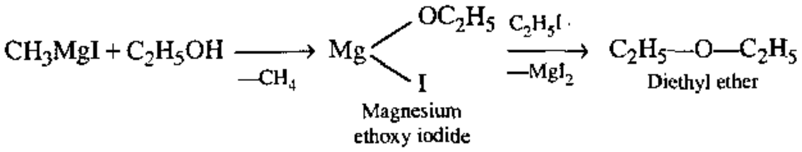
(a) Ethyl acetate :



$$CH_3MgI + \underset{\text{Chloroformic ester}}{ClCOOC_2H_5} \longrightarrow \underset{\text{Ethyl acetate}}{CH_3COOC_2H_5} + Mg\begin{smallmatrix}I\\Cl\end{smallmatrix}$$

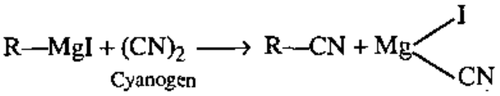
(10) Formation of ethers : Grignard reagent reacts with alcohol and alkyl halide, respectively to form ether.

(a) Diethyl ether :



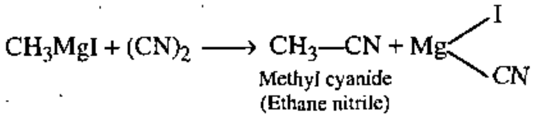
$$CH_3MgI + C_2H_5OH \xrightarrow[-CH_4]{} \underset{\substack{\text{Magnesium}\\\text{ethoxy iodide}}}{Mg\begin{smallmatrix}OC_2H_5\\I\end{smallmatrix}} \xrightarrow[-MgI_2]{C_2H_5I} \underset{\text{Diethyl ether}}{C_2H_5{-}O{-}C_2H_5}$$

(11) Formation of cyanides or nitriles :



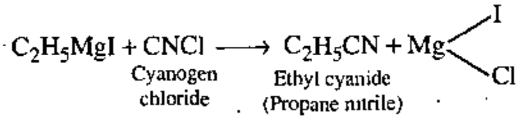
$$R{-}MgI + \underset{\text{Cyanogen}}{(CN)_2} \longrightarrow R{-}CN + Mg\begin{smallmatrix}I\\CN\end{smallmatrix}$$

(a) Methyl cyanide :



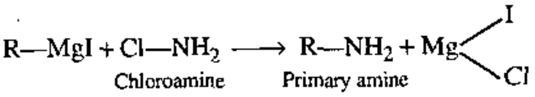
$$CH_3MgI + (CN)_2 \longrightarrow \underset{\substack{\text{Methyl cyanide}\\\text{(Ethane nitrile)}}}{CH_3{-}CN} + Mg\begin{smallmatrix}I\\CN\end{smallmatrix}$$

(b) Ethyl cyanide :



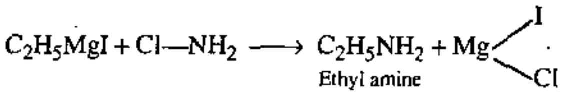
$$C_2H_5MgI + \underset{\substack{\text{Cyanogen}\\\text{chloride}}}{CNCl} \longrightarrow \underset{\substack{\text{Ethyl cyanide}\\\text{(Propane nitrile)}}}{C_2H_5CN} + Mg\begin{smallmatrix}I\\Cl\end{smallmatrix}$$

(12) Formation of amines : Grignard reagent reacts with chloroamine to form primary amines.



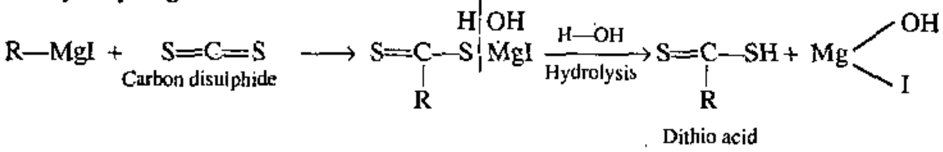
$$R{-}MgI + \underset{\text{Chloroamine}}{Cl{-}NH_2} \longrightarrow \underset{\text{Primary amine}}{R{-}NH_2} + Mg\begin{smallmatrix}I\\Cl\end{smallmatrix}$$

Ethyl amine :



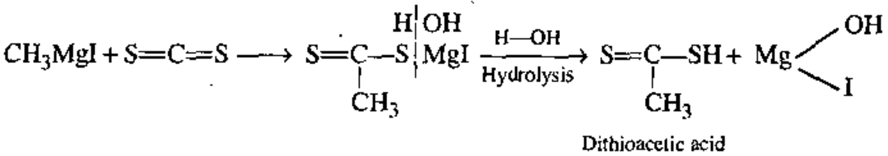
$$C_2H_5MgI + Cl—NH_2 \longrightarrow \underset{\text{Ethyl amine}}{C_2H_5NH_2} + Mg\begin{matrix} I \\ Cl \end{matrix}$$

(13) Formation of dithionic acids : Grignard reagent reacts with CS_2 to give a product which on hydrolysis gives dithionic acid.



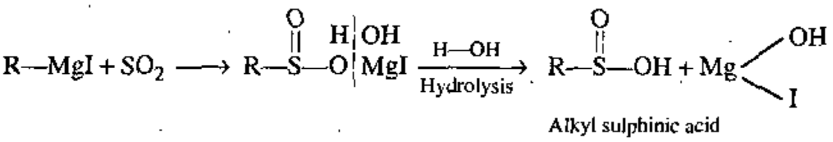
$$R—MgI + \underset{\text{Carbon disulphide}}{S{=}C{=}S} \longrightarrow S{=}\underset{R}{C}—S\,MgI \xrightarrow[\text{Hydrolysis}]{H—OH} \underset{\text{Dithio acid}}{S{=}\underset{R}{C}—SH} + Mg\begin{matrix} OH \\ I \end{matrix}$$

Dithioacetic acid :



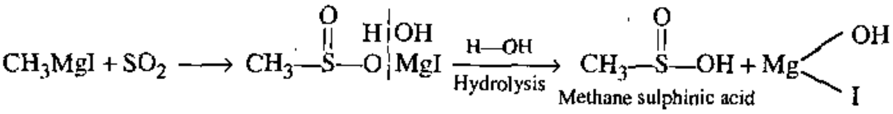
$$CH_3MgI + S{=}C{=}S \longrightarrow S{=}\underset{CH_3}{C}—S\,MgI \xrightarrow[\text{Hydrolysis}]{H—OH} \underset{\text{Dithioacetic acid}}{S{=}\underset{CH_3}{C}—SH} + Mg\begin{matrix} OH \\ I \end{matrix}$$

(14) Formation of sulphinic acids : Grignard reagent reacts with SO_2 to give a product which on hydrolysis gives sulphinic acid.



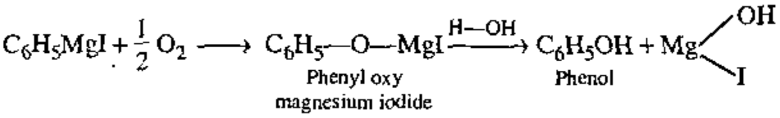
$$R—MgI + SO_2 \longrightarrow R—\overset{O}{\overset{\|}{S}}—O\,MgI \xrightarrow[\text{Hydrolysis}]{H—OH} \underset{\text{Alkyl sulphinic acid}}{R—\overset{O}{\overset{\|}{S}}—OH} + Mg\begin{matrix} OH \\ I \end{matrix}$$

Methane sulphinic acid :



$$CH_3MgI + SO_2 \longrightarrow CH_3—\overset{O}{\overset{\|}{S}}—O\,MgI \xrightarrow[\text{Hydrolysis}]{H—OH} \underset{\text{Methane sulphinic acid}}{CH_3—\overset{O}{\overset{\|}{S}}—OH} + Mg\begin{matrix} OH \\ I \end{matrix}$$

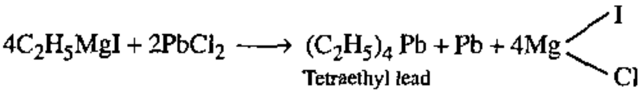
(15) Formation of phenol : Grignard reagent reacts with oxygen to give a product which on hydrolysis gives phenol.



$$C_6H_5MgI + \frac{1}{2}O_2 \longrightarrow \underset{\substack{\text{Phenyl oxy} \\ \text{magnesium iodide}}}{C_6H_5—O—MgI} \xrightarrow{H—OH} \underset{\text{Phenol}}{C_6H_5OH} + Mg\begin{matrix} OH \\ I \end{matrix}$$

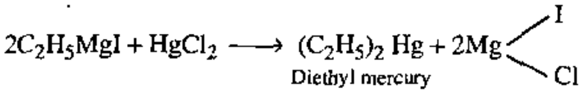
(16) Formation of other organometallic compounds : Some metal chlorides react with Grignard reagent to form different organometallic compounds.

(a) Tetraethyl lead (TEL) :



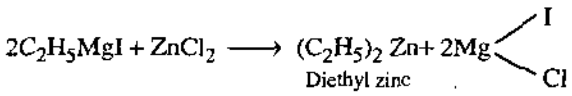
$$4C_2H_5MgI + 2PbCl_2 \longrightarrow \underset{\text{Tetraethyl lead}}{(C_2H_5)_4\,Pb} + Pb + 4Mg\begin{matrix} I \\ Cl \end{matrix}$$

(b) Diethyl mercury :



$$2C_2H_5MgI + HgCl_2 \longrightarrow \underset{\text{Diethyl mercury}}{(C_2H_5)_2\,Hg} + 2Mg\begin{matrix} I \\ Cl \end{matrix}$$

(c) Diethyl zinc (Frankland reagent) :



$$2C_2H_5MgI + ZnCl_2 \longrightarrow \underset{\text{Diethyl zinc}}{(C_2H_5)_2\,Zn} + 2Mg\begin{matrix} I \\ Cl \end{matrix}$$

• 3.3. ORGANOLITHIUM COMPOUNDS

Organolithium compounds are those compounds which contain C—Li bond, *e.g.*,

$CH_3—Li$	$C_2H_5—Li$	$C_6H_5—Li$
Methyllithium	Ethyllithium	Phenyllithium

These compounds behave in the same way as Grignard's reagents but with increased reactivity. The increased reactivity is due to the greater polar character of C—Li in comparison to C—Mg bond.

[I] Methods of Preparation

(i) By the interaction of lithium with an alkyl or an aryl halide in benzene or ether at low temperature.

$$R{-}X + 2Li \longrightarrow R{-}Li + LiX$$

$$CH_3{-}I + 2Li \longrightarrow CH_3{-}Li + LiI$$

$$C_2H_5Cl + 2Li \longrightarrow \underset{\text{Ethyl lithium}}{C_2H_5{-}Li} + LiCl$$

$$C_6H_5Cl + 2Li \longrightarrow C_6H_5{-}Li + LiCl$$

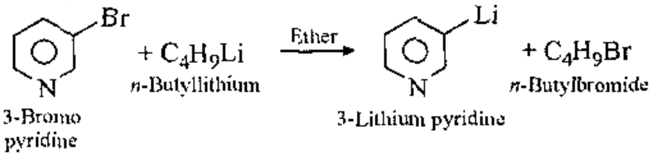
(ii) From organomercury compounds : By treating lithium with organomercury compounds in the presence of benzene

$$R_2Hg + 2Li \xrightarrow{\text{benzene}} 2R{-}Li + Hg$$

$$(CH_3)_2Hg + 2Li \xrightarrow{\text{benzene}} 2CH_3{-}Li + Hg$$

(iii) By metal halogen exchange in ether : *Lithium aryls are best prepared by this method.*

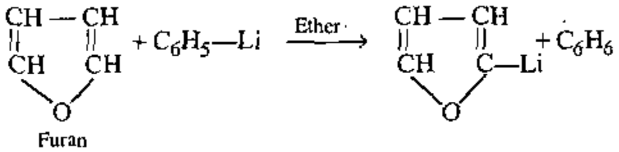
$$\underset{\text{Phenyl bromide}}{C_6H_5Br} + \underset{n\text{-Butyllithium}}{C_4H_9Li} \xrightarrow{\text{Ether}} \underset{\text{Phenyllithium}}{C_6H_5{-}Li} + C_4H_9Br$$

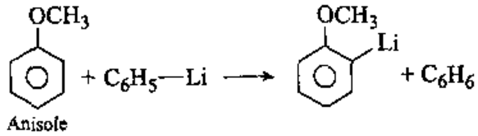


(iv) By metal-metal exchange reactions : Vinyl allyl and other unsaturated derivatives of lithium can be obtained by metal-metal exchange reactions.

$$Sn(CH{=}CH_2)_4 + 4C_6H_5{-}Li \longrightarrow 4Li(CH{=}CH_2) + Sn(C_6H_5)_4$$

(v) By metal-hydrogen exchange in ether :





[II] Properties

(i) Organolithium compounds are colourless volatile liquids or low melting solids. They are *thermally unstable and decompose to* LiH and an alkene on standing at room temperature. They are covalent and are soluble in benzene and other non-polar solvents. They are rapidly hydrolysed by water.

(ii) Organolithium compounds are synthetic reagents and they can be used for the synthesis of number of compounds as given below :

(a) Formation of hydrocarbons : Organolithium compounds react with compounds containing active hydrogen such as water, alcohol to give the corresponding hydrocarbons.

$$R{-}Li + H_2O \longrightarrow R{-}H + LiOH$$

$$CH_3{-}Li + H_2O \longrightarrow CH_4 + LiOH$$

$$C_2H_5Li + C_2H_5OH \longrightarrow C_2H_6 + C_2H_5OLi$$

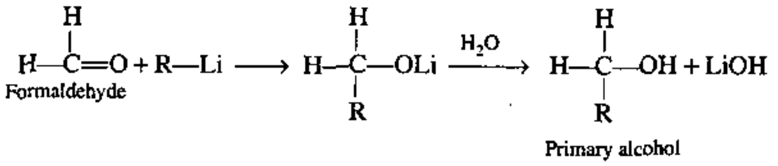
(b) Formation of alkyl halides : *Organolithium compounds are decomposed by* halogens to form alkyl halides.

$$R{-}Li + X_2 \longrightarrow R{-}X + LiX$$

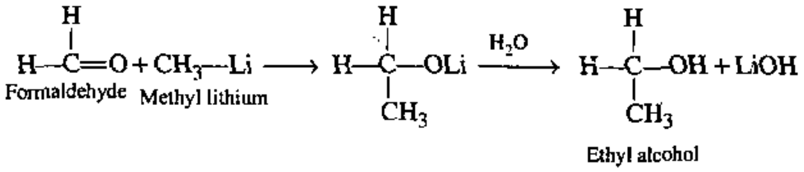
$$C_2H_5{-}Li + Br_2 \longrightarrow \underset{\text{Ethyl bromide}}{C_2H_5Br} + LiBr$$

(c) Formation of alcohols :

(i) Primary alcohols : Organolithium compounds react with HCHO to form an addition product which on hydrolysis form primary alcohols.

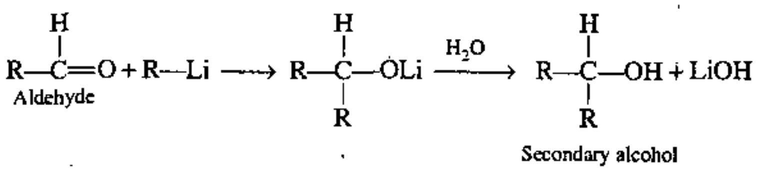


$$\underset{\text{Formaldehyde}}{\mathrm{H{-}\overset{H}{C}{=}O}} + \mathrm{R{-}Li} \longrightarrow \mathrm{H{-}\overset{H}{\underset{R}{C}}{-}OLi} \xrightarrow{H_2O} \underset{\text{Primary alcohol}}{\mathrm{H{-}\overset{H}{\underset{R}{C}}{-}OH}} + \mathrm{LiOH}$$

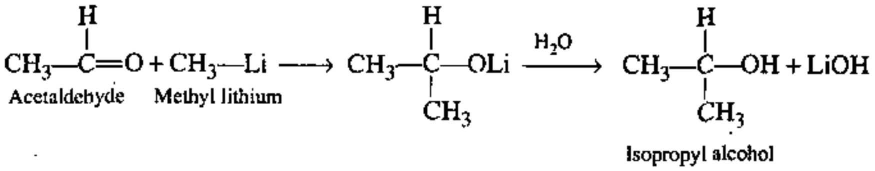


$$\underset{\text{Formaldehyde}}{\mathrm{H{-}\overset{H}{C}{=}O}} + \underset{\text{Methyl lithium}}{\mathrm{CH_3{-}Li}} \longrightarrow \mathrm{H{-}\overset{H}{\underset{CH_3}{C}}{-}OLi} \xrightarrow{H_2O} \underset{\text{Ethyl alcohol}}{\mathrm{H{-}\overset{H}{\underset{CH_3}{C}}{-}OH}} + \mathrm{LiOH}$$

(ii) Secondary alcohols : Organolithium compounds react with aldehydes other than formaldehyde to form an addition product which on hydrolysis form secondary alcohols.

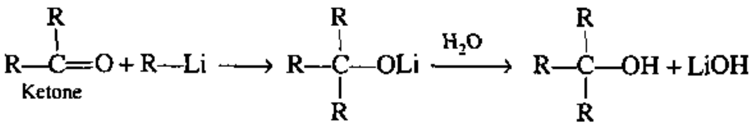


$$\underset{\text{Aldehyde}}{\mathrm{R{-}\overset{H}{C}{=}O}} + \mathrm{R{-}Li} \longrightarrow \mathrm{R{-}\overset{H}{\underset{R}{C}}{-}OLi} \xrightarrow{H_2O} \underset{\text{Secondary alcohol}}{\mathrm{R{-}\overset{H}{\underset{R}{C}}{-}OH}} + \mathrm{LiOH}$$

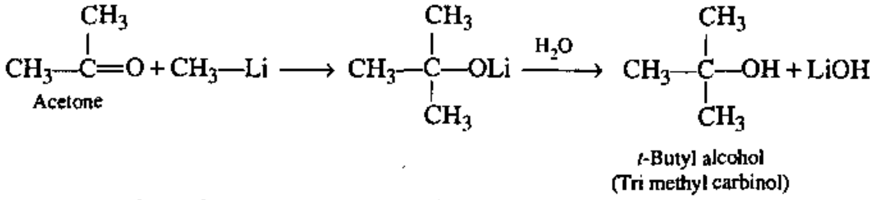


$$\underset{\text{Acetaldehyde}}{\mathrm{CH_3{-}\overset{H}{C}{=}O}} + \underset{\text{Methyl lithium}}{\mathrm{CH_3{-}Li}} \longrightarrow \mathrm{CH_3{-}\overset{H}{\underset{CH_3}{C}}{-}OLi} \xrightarrow{H_2O} \underset{\text{Isopropyl alcohol}}{\mathrm{CH_3{-}\overset{H}{\underset{CH_3}{C}}{-}OH}} + \mathrm{LiOH}$$

(iii) Tertiary alcohols : Organolithium compounds react with ketones to form an addition product which on hydrolysis form tertiary alcohol.



$$\underset{\text{Ketone}}{\mathrm{R{-}\overset{R}{C}{=}O}} + \mathrm{R{-}Li} \longrightarrow \mathrm{R{-}\overset{R}{\underset{R}{C}}{-}OLi} \xrightarrow{H_2O} \mathrm{R{-}\overset{R}{\underset{R}{C}}{-}OH} + \mathrm{LiOH}$$



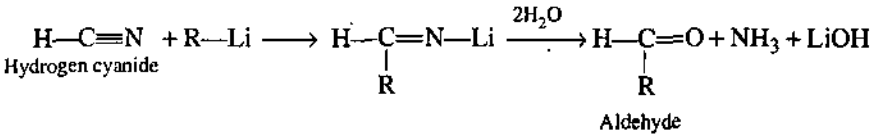
$$\underset{\text{Acetone}}{\mathrm{CH_3{-}\overset{CH_3}{C}{=}O}} + \mathrm{CH_3{-}Li} \longrightarrow \mathrm{CH_3{-}\overset{CH_3}{\underset{CH_3}{C}}{-}OLi} \xrightarrow{H_2O} \underset{\substack{\text{t-Butyl alcohol}\\ \text{(Tri methyl carbinol)}}}{\mathrm{CH_3{-}\overset{CH_3}{\underset{CH_3}{C}}{-}OH}} + \mathrm{LiOH}$$

(d) Formation of ethers : Higher ethers are prepared by the action of organolithium compounds on a monochloro ether.

$$\underset{\substack{\text{Monochloro}\\ \text{ether}}}{\mathrm{R{-}O{-}CH_2{-}}\boxed{\mathrm{Cl + Li}}}\mathrm{{-}R'} \longrightarrow \mathrm{R{-}O{-}CH_2{-}R'} + \mathrm{LiCl}$$

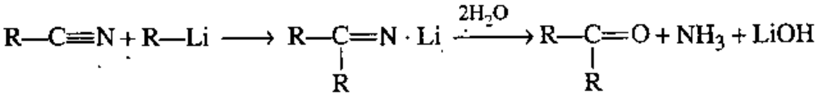
$$\underset{\substack{\text{Chlorodimethyl}\\ \text{ether}}}{\mathrm{CH_3{-}O{-}CH_2{-}}\boxed{\mathrm{Cl + Li}}}\mathrm{{-}CH_3} \longrightarrow \underset{\substack{\text{Ethylmethyl}\\ \text{ether}}}{\mathrm{CH_3{-}O{-}CH_2{-}CH_3}} + \mathrm{LiCl}$$

(e) Formation of aldehydes : Organolithium compounds react with hydrogen cyanide to form an addition product which on hydrolysis give aldehydes

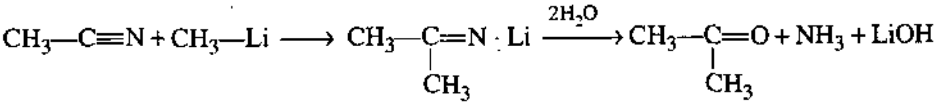


$$\underset{\text{Hydrogen cyanide}}{\mathrm{H{-}C{\equiv}N}} + \mathrm{R{-}Li} \longrightarrow \mathrm{H{-}\underset{R}{C}{=}N{-}Li} \xrightarrow{2H_2O} \underset{\text{Aldehyde}}{\mathrm{H{-}\underset{R}{C}{=}O}} + \mathrm{NH_3} + \mathrm{LiOH}$$

(f) Formation of ketones : Organolithium compounds react with alkyl cyanides to form an addition product which on hydrolysis give ketones.

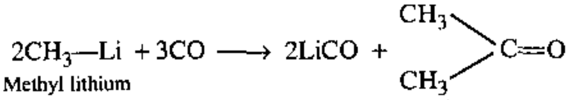


$$R{-}C{\equiv}N + R{-}Li \longrightarrow \underset{R}{\underset{|}{R{-}C}}{=}N \cdot Li \xrightarrow{2H_2O} \underset{\text{Ketone}}{\underset{R}{\underset{|}{R{-}C}}{=}O} + NH_3 + LiOH$$



$$CH_3{-}C{\equiv}N + CH_3{-}Li \longrightarrow \underset{CH_3}{\underset{|}{CH_3{-}C}}{=}N \cdot Li \xrightarrow{2H_2O} \underset{\text{Acetone}}{\underset{CH_3}{\underset{|}{CH_3{-}C}}{=}O} + NH_3 + LiOH$$

Ketones are also obtained when organolithium compounds react with CO or CO_2



$$\underset{\text{Methyl lithium}}{2CH_3{-}Li} + 3CO \longrightarrow 2LiCO + \underset{\text{Acetone}}{(CH_3)_2C{=}O}$$

(g) Formation of amines : Organolithium compounds react with chloro amines to form alkyl amines

$$R{-}Li + \underset{\text{Chloro amine}}{Cl{-}NH_2} \longrightarrow R{-}NH_2 + LiCl$$

$$C_2H_5Li + \underset{\text{Chloro amine}}{Cl{-}NH_2} \longrightarrow \underset{\text{Ethyl amine}}{C_2H_5{-}NH_2} + LiCl$$

(h) Formation of alkyl cyanides : Organo lithium compounds react with cyanogen chloride to form alkyl cyanides.

$$R{-}Li + \underset{\substack{\text{Cyanogen}\\\text{chloride}}}{Cl{-}CN} \longrightarrow \underset{\text{Alkyl cyanide}}{R{-}CN} + LiCl$$

$$CH_3{-}Li + \underset{\substack{\text{Cyanogen}\\\text{chloride}}}{Cl{-}CN} \longrightarrow \underset{\text{Methyl cyanide}}{CH_3{-}CN} + LiCl$$

(i) Formation of thioalcohols or mercaptans : Organolithium compounds react with sulphur to form thioalcohols.

$$R{-}Li + S \longrightarrow R{-}S{-}Li \xrightarrow{H_2O} \underset{\text{Thioalcohol}}{R{-}SH} + LiOH$$

$$C_2H_5{-}Li + S \longrightarrow C_2H_5{-}S{-}Li \xrightarrow{H_2O} \underset{\text{Ethyl mercaptan}}{C_2H_5SH} + LiOH$$

(j) Formation of other organometallic compounds : Organolithium compounds react with metal halides to form other organometallic compounds.

$$3CH_3{-}Li + BCl_3 \longrightarrow \underset{\text{Trimethyl boron}}{(CH_3)_3B} + 3LiCl$$

$$4CH_3{-}Li + SnCl_4 \longrightarrow \underset{\text{Tetramethyl tin}}{(CH_3)_4Sn} + 4LiCl$$

$$2CH_3{-}Li + CdCl_2 \longrightarrow \underset{\text{Dimethyl cadmium}}{(CH_3)_2Cd} + 2LiCl$$

$$4C_2H_5{-}Li + 2PbCl_2 \longrightarrow \underset{\text{Tetraethyl lead}}{(C_2H_5)_4Pb} + Pb + 4LiCl$$

[III] Uses

Organolithium compounds are used for :

(i) converting alkenes and dienes to elastomers.

(ii) the synthesis of different types of organic compounds.

• 3.4. ORGANOSULPHUR COMPOUNDS

[I] Thiols or Mercaptans

When sulphur atom is present in place of oxygen in an alcohol (ROH), the corresponding alcohol is known as *thiol* (RSH) *or mercaptan.* It is also known as *thioalcohol.* The IUPAC name of thio alcohol is thiol.

$$\underset{\text{Alcohol}}{R.OH} \xrightarrow[+S]{-O} \underset{\text{Thiol}}{R.SH}$$

$$C_2H_5OH \xrightarrow[+S]{-O} \underset{\substack{\text{Ethyl mercaptan}\\ \text{(Ethanethiol)}}}{C_2H_5SH}$$

These compounds may also be taken as derivatives of H_2S in which H-atom of H_2S has been replaced by alkyl group.

$$H{-}S{-}H \xrightarrow[+R]{-H} R{-}SH$$

$$H{-}S{-}H \xrightarrow[+C_2H_5]{-H} \underset{\text{Ethyl mercaptan}}{C_2H_5{-}SH}$$

These compounds are weakly acidic and react with mercuric ions to form mercury salts. Hence, these compounds are called as mercaptans (mercury catching).

[II] Methods of Preparation

The general methods of preparation of thiols are as follows :

(1) From alcohols :

(a) Thiols are formed when alcohols are heated with phosphorus pentasulphide (P_2S_5).

$$\underset{\text{Alcohol}}{5R.OH} + P_2S_5 \xrightarrow{\Delta} \underset{\text{Thiol}}{5R.SH} + P_2O_5$$

$$\underset{\text{Ethanol}}{5C_2H_5OH} + P_2S_5 \xrightarrow{\Delta} \underset{\substack{\text{Ethanethiol}\\ \text{(or Ethyl mercaptan)}}}{5C_2H_5.SH} + P_2O_5$$

(b) Thiols are found by passing the mixture of alcohol vapours and hydrogen sulphide over heated catalyst, *e.g.*, thoria (ThO_2).

$$R.O.H + H_2S \xrightarrow[400^\circ C]{ThO_2} R.S.H + H_2O$$

$$C_2H_5OH + H_2S \xrightarrow[400^\circ C]{ThO_2} C_2H_5SH + H_2O$$

(2) From alkyl halides : When alkyl halides are heated with an alcoholic solution of sodium or potassium hydrosulphide, thioalcohols are formed.

$$\underset{\substack{\text{Alkyl}\\ \text{halide}}}{R.X} + \underset{\substack{\text{Potassium}\\ \text{hydrosulphide}}}{K.SH} \xrightarrow{\Delta} \underset{\text{Thiol}}{RSH} + KX$$

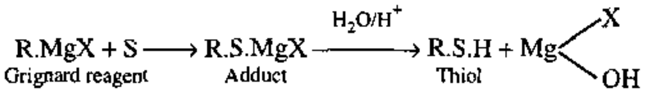
$$C_2H_5Cl + K.SH \xrightarrow{\Delta} \underset{\text{Ethanethiol}}{C_2H_5SH} + KCl$$

(3) From disulphides : On reducing dialkyl disulphides (R.S.S.R.) with zinc and acid, thiols are found.

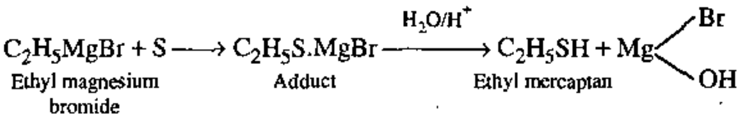
$$R.S.S.R + 2H \xrightarrow{Zn/H_2SO_4} 2R.SH$$

$$\underset{\text{Diethyl disulphide}}{C_2H_5.S.S.C_2H_5} + 2H \xrightarrow{Zn/H_2SO_4} \underset{\text{Ethyl mercaptan}}{2C_2H_5.SH}$$

(4) From Grignard reagents : Grignard reagent on reaction with sulphur gives an adduct which on hydrolysis gives thiol.



$$\underset{\text{Grignard reagent}}{R.MgX} + S \longrightarrow \underset{\text{Adduct}}{R.S.MgX} \xrightarrow{H_2O/H^+} \underset{\text{Thiol}}{R.S.H} + Mg\begin{matrix}X\\ OH\end{matrix}$$



$$\underset{\substack{\text{Ethyl magnesium}\\ \text{bromide}}}{C_2H_5MgBr} + S \longrightarrow \underset{\text{Adduct}}{C_2H_5S.MgBr} \xrightarrow{H_2O/H^+} \underset{\text{Ethyl mercaptan}}{C_2H_5SH} + Mg\begin{matrix}Br\\ OH\end{matrix}$$

[III] Physical Properties

(1) Methanethiol is a gas, while higher homologues are *volatile liquids having unpleasant* odour. The boiling points of methanethiol and ethanethiol are 6° and 37°C, respectively.

(2) The boiling points of *thiols* are *much lower than the corresponding alcohols* which is due to the weaker intermolecular hydrogen bonding in thiols than alcohols.

(3) *They are less soluble in water,* as compared to corresponding alcohols. However, they are readily soluble in organic solvents, *e.g.*, ether, alcohol etc.

(4) Thiols are *weak acids.* They are fairly strong acids as compared to alcohols because the larger sulphur atom can accommodate the negative charge of the anion much more readily than oxygen.

[IV] Chemical Properties

Thiols are less stable than corresponding oxygen compounds and hence are chemically more reactive.

[A] Characteristics similar to alcohols

(1) ***Reaction with alkali metals :*** Thiols form mercaptides.

$$2C_2H_5SH + 2Na \longrightarrow \underset{\text{Sodium ethyl mercaptide}}{2C_2H_5SNa} + H_2$$

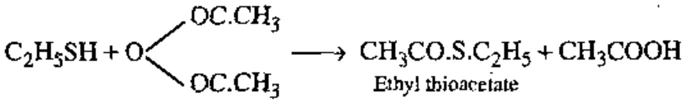
(2) ***Reaction with alkalies :*** Thiols form mercaptides.

$$C_2H_5SH + NaOH \longrightarrow \underset{\text{Sodium mercaptide}}{C_2H_5SNa} + H_2O$$

(3) ***Reaction with acids and acid derivatives :*** Thiols form thioesters.

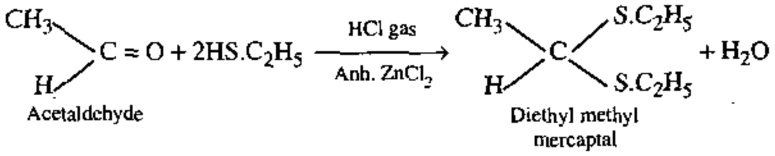
$$C_2H_5SH + \underset{\text{Acetic acid}}{HO.OC.CH_3} \xrightarrow{H^+} \underset{\text{Ethyl thioacetate}}{CH_3CO.S.C_2H_5} + H_2O$$

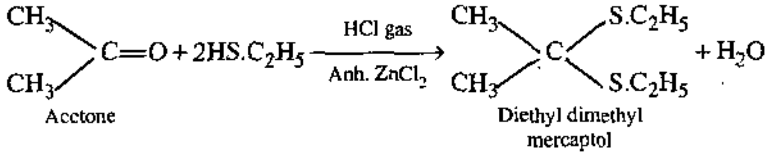
$$C_2H_5SH + \underset{\text{Acetyl chloride}}{Cl.CO.CH_3} \longrightarrow CH_3.CO.S.C_2H_5 + HCl$$



$$C_2H_5SH + \underset{\text{Acetic anhydride}}{O(OC.CH_3)_2} \longrightarrow \underset{\text{Ethyl thioacetate}}{CH_3CO.S.C_2H_5} + CH_3COOH$$

(4) ***Reaction with aldehydes and ketones :*** Thiols form thioacetals or mercaptals with aldehydes and thioketals or mercaptols with ketones.





[B] Characteristics different from alcohols

(5) ***Reaction with alkalies :*** Thiols behave as weak acids and dissolve readily in alkalies to form mercaptides.

$$C_2H_5SH + NaOH \longrightarrow \underset{\text{Sodium ethyl mercaptide}}{C_2H_5S.Na} + H_2O$$

(6) ***Reaction with metallic salts and metallic oxides :***

(*a*) With metallic oxides, thiols form mercaptides.

$$2C_2H_5SH + HgO \longrightarrow \underset{\text{Mercury ethyl mercaptide}}{(C_2H_5S)_2Hg} + H_2O$$

(b) On treatment with aqueous solution of metallic salts, mercaptides are obtained as precipitates.

$$2C_2H_5SH + (CH_3COO)_2Pb \longrightarrow \underset{\text{Lead ethyl mercaptide}}{(C_2H_5S)_2Pb} + 2CH_3COOH$$

(c) On reaction with aqueous solution of cupric chloride or an alkaline solution of sodium plumbite in presence of sulphur, thiols form disulphides.

$$2C_2H_5SH + 2CuCl_2 \longrightarrow \underset{\text{Diethyl disulphide}}{C_2H_5.S.S.C_2H_5} + Cu_2Cl_2 + 2HCl$$

$$2C_2H_5SH + \underset{\text{Sodium plumbite}}{Na_2PbO_2} + S \longrightarrow C_2H_5.S.S.C_2H_5 + PbS + 2NaOH$$

(7) Oxidation :

(a) With mild oxidising agents like air, H_2O_2, $CuCl_2$, I_2, NaOCl or $FeCl_3$ etc. thiols are oxidised to disulphides.

$$C_2H_5SH + H_2O_2 \longrightarrow C_2H_5.S.S.C_2H_5 + 2H_2O$$

$$C_2H_5S\boxed{H + I_2 + H}S\,C_2H_5 \longrightarrow \underset{\text{Diethyl disulphide}}{C_2H_5{-}S{-}S{-}C_2H_5} + 2HI$$

(b) With strong oxidising agents like HNO_3, $KMnO_4$, thiols are oxidised to sulphonic acids.

$$5C_2H_5SH + 6MnO_4^- + 18H^+ \longrightarrow \underset{\text{Ethyl sulphonic acid}}{5C_2H_5SO_3H} + 6Mn^{2+} + 9H_2O$$

[V] Uses

(1) Due to their extremely unpleasant smell, lower thiols are used to detect minor leakages in natural and coal gas pipes.

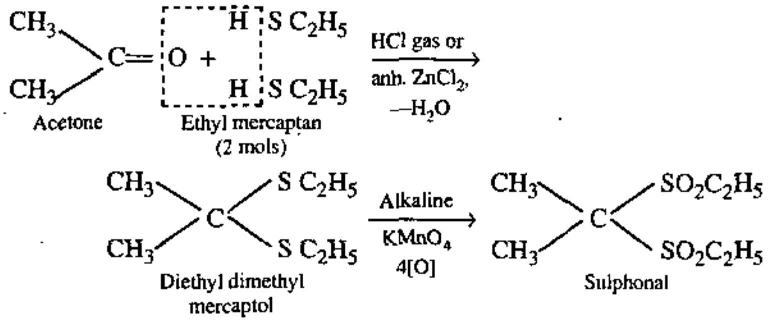
(2) Lower thiols are used in the preparation of some fungicides.

(3) Thiols are used for healing the wounds.

(4) Thiols are used for preparing sulphonal $[(CH_3)_2\,C\,(SO_2C_2H_5)_2]$ and other hypnotics.

• 3.5. PREPARATION OF SULPHONAL

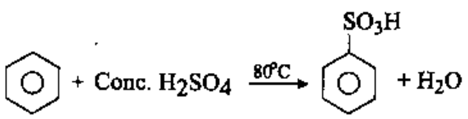
Acetone reacts with ethyl mercaptan in presence of HCl gas or anhydrous zinc chloride to give diethyl dimethyl mercaptol which on oxidation with alkaline $KMnO_4$ gives sulphonal which is used as hypnotic (sleep producing drug).



• 3.6. AROMATIC SULPHONIC COMPOUNDS

[I] Sulphonation

The replacement of one or more hydrogen atoms of benzene nucleus by $-SO_3H$ *groups is known as sulphonation.* This is brought about by conc. H_2SO_4, fuming sulphuric acid or chlorosulphonic acid.



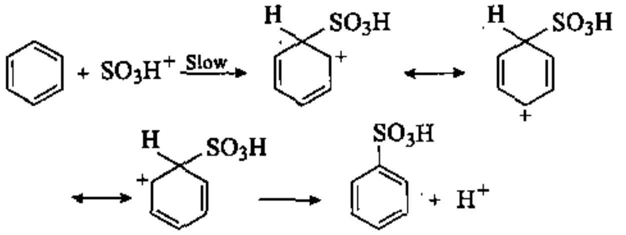
The number of $-SO_3H$ groups that enter in the benzene nucleus depend upon (i) temperature, (ii) nature of sulphonating agent and (iii) nature of substance to be sulphonated. Ortho – and para-directing groups such as $-OH$, $-NH_2$, $-CH_3$ help sulphonation, whereas meta-directing groups such as $-NO_2$, $-COOH$ retard it.

[II] Mechanism of Sulphonation

Sulphonation takes place due to the attack of electrophilic reagent, SO_3H^+. This ion is obtained by the dehydration of sulphuric acidium ion.

$$H_2SO_4 + H_2SO_4 \longrightarrow \underset{\text{Sulphuric acidium ion}}{[H_3SO_4]^+} + HSO_4^-$$

$$[H_3SO_4]^+ \xrightarrow[-H_2O]{} \underset{\text{Sulphonium ion}}{SO_3H^+}$$

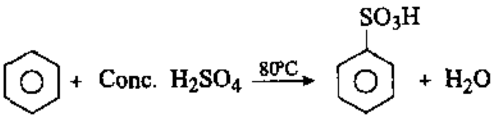


$$H^+ + HSO_4^- \longrightarrow H_2SO_4$$

Why more than three sulphonic groups cannot be introduced into the benzene ring?
More than three $-SO_3H$ groups cannot be introduced into the benzene nucleus. This is because $-SO_3H$ group is meta directing and benzene nucleus has only three meta positions. When all the three meta positions are occupied, further sulphonation in the benzene nucleus becomes impossible. Due to meta directing influence, the $-SO_3H$ group is inactive and reduces the reactivity of benzene nucleus. With the introduction of $-SO_3H$ group, the benzene nucleus becomes *inactive with the result that the introduction of second and third $-SO_3H$ groups becomes* extremely difficult in the benzene nucleus.

[III] Preparation

In laboratory, benzene sulphonic acid is prepared by the action of conc. H_2SO_4 on benzene at 80°C.



Benzene sulphonic acid

Benzene (1 part) and conc. H_2SO_4 (two parts) are taken in a round bottomed flask with a reflux condenser. The flask is heated slowly on a sand bath. The flask is shaken and when whole *of the benzene is dissolved, the flask is cooled.* The product is poured into water and this solution is treated with $BaCO_3$. The excess of H_2SO_4 is precipitated as $BaSO_4$ and benzene sulphonic acid remains in solution as its barium salt.

$$H_2SO_4 + BaCO_3 \longrightarrow \underset{\text{Ppt.}}{BaSO_4} + H_2O + CO_2\uparrow$$

$$2C_6H_5SO_3H + BaCO_3 \longrightarrow \underset{\text{Barium benzene sulphonate}}{(C_6H_5SO_3)_2Ba} + H_2O + CO_2$$

The precipitate of $BaSO_4$ is filtered and the solution is concentrated when barium benzene sulphonate crystallizes out. A weighed quantity of these crystals is decomposed by calculated quantity of dil. H_2SO_4. The precipitate of $BaSO_4$ is filtered off and the solution is concentrated to get the crystals of benzene sulphonic acid.

$$\underset{\text{Barium benzene sulphonate}}{(C_6H_5SO_3)_2Ba} + H_2SO_4 \longrightarrow BaSO_4 + \underset{\text{Benzene sulphonic acid}}{2C_6H_5SO_3H}$$

[IV] Manufacture

The manufacture of benzene sulphonic acid is similar to that of laboratory method. The only difference is that the sulphonation is carried out in a container fitted with steam coils and a mechanical stirrer.

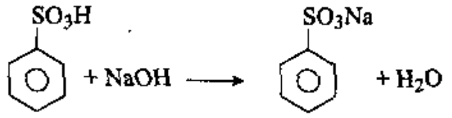
[V] Physical Properties

Benzene sulphonic acid is a colourless solid, M. Pt. 44°C. It is very soluble in water and gives a strongly acidic solution.

[VI] Chemical Properties

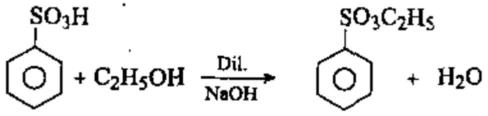
(1) Reactions due to – SO_3H group.

(a) Salt formation : Benzene sulphonic acid reacts with bases to form salts.



Sodium benzene sulphonate

(b) Ester formation : Benzene sulphonic acid reacts with C_2H_5OH in presence of dil. NaOH to form ester.



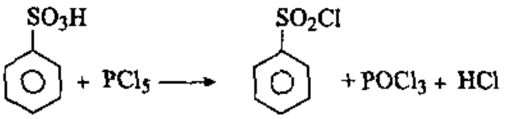
Ethyl benzene sulphonate

(c) Reaction with carbonate salts : Benzene sulphonic acid decomposes metal carbonates to form CO_2.

$$2C_6H_5SO_3H + BaCO_3 \longrightarrow (C_6H_5SO_3)_2Ba + H_2O + CO_2$$

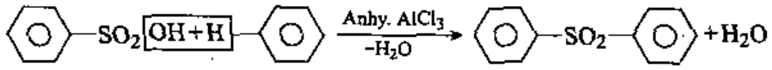
Barium benzene sulphonate

(d) Reaction with PCl_5 : Benzene sulphonic acid gives benzene sulphonyl chloride (Hinsberg reagent) with PCl_5.



Benzene sulphonyl chloride

(e) Reaction with hydrocarbons : Benzene sulphonic acid gives sulphone compounds with benzene.



Benzene

Diphenyl sulphone

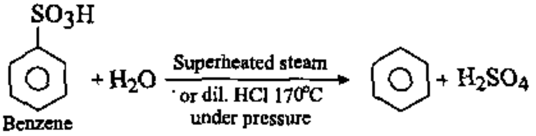
(f) Reaction with dehydrating agent : On heating benzene sulphonic acid with P_2O_5, benzene sulphonic anhydride is formed.

$$2C_6H_5SO_2OH \xrightarrow[-H_2O]{P_2O_5} (C_6H_5SO_2)_2O$$

Benzene sulphonic anhydride

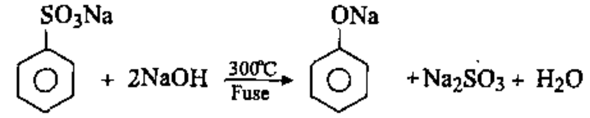
(g) Reactions involving replacement of – SO_3H group.

(i) Substitution by hydrogen : Benzene sulphonic acid on heating with super-heated steam or with dil. HCl at 170°C under pressure gives benzene. The reaction is known as *desulphonation*.



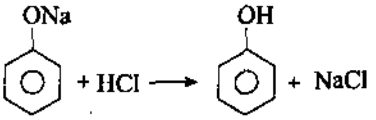
Benzene sulphonic acid

(ii) Substitution by hydroxyl group : Sodium salt of benzene sulphonic acid when fused with solid NaOH, gives sodium phenoxide which on treatment with mineral acid gives phenol.



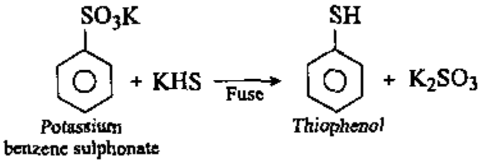
Sodium benzene sulphanate

Sodium phenoxide

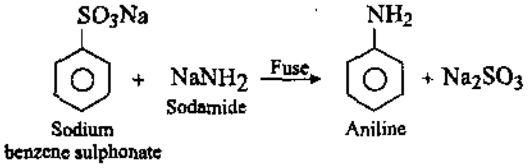


Phenol

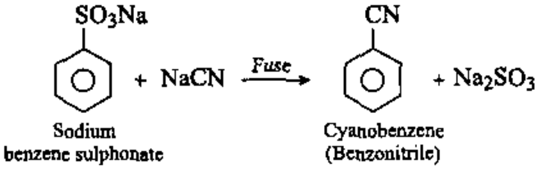
(iii) Substitution by – SH group : Potassium salt of benzene sulphonic acid when fused with potassium hydrogen sulphide (KHS), gives thiophenol.



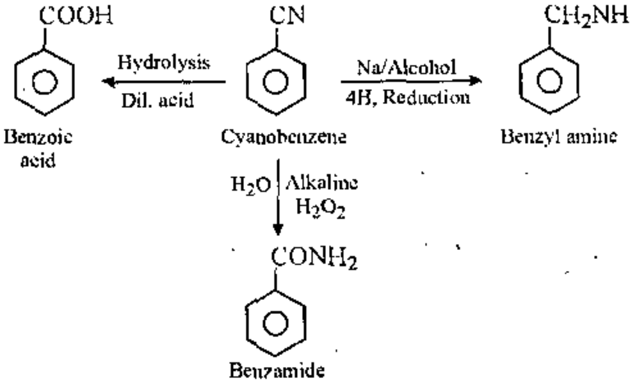
(iv) Substitution by $-NH_2$ group : Sodium salt of benzene sulphonic acid when fused with sodamide gives aniline.



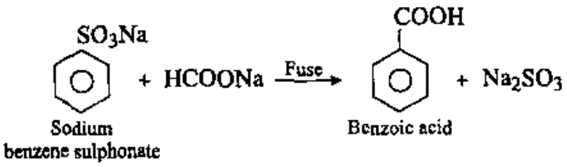
(v) Substitution by – CN group : Sodium salt of benzene sulphonic acid when fused with solid NaCN gives cyanobenzene.



Cyanobenzene on reduction with sodium and alcohol gives benzyl amine, on hydrolysis with dil. acids gives benzoic acid and on hydrolysis by alkaline H_2O_2 gives benzamide.



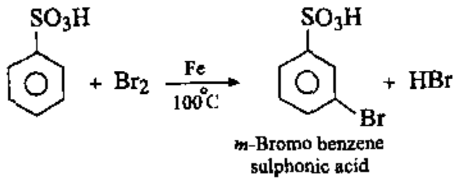
(iv) Substitution by– COOH group : Sodium salt of the acid when fused with sodium formate gives benzoic acid.



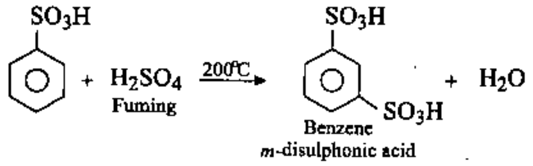
(2) Reactions due to benzene nucleus

The directive influence of $-SO_3H$ group is meta directing, therefore, substitution takes place in the meta position as shown in halogenation, sulphonation, nitration etc. as follows :

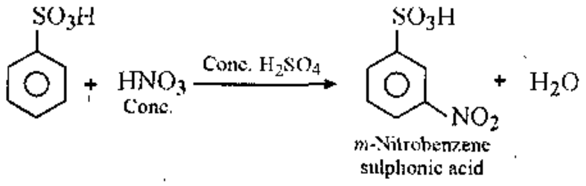
(a) Halogenation :



(b) Sulphonation :



(c) Nitration :



[VII] Structure of Benzene Sulphonic Acid

(1) Molecular formula : Elementary analysis and molecular weight determination shows that molecular formula of benzene sulphonic acid is $C_6H_6SO_3$.

(2) Presence of phenyl (C_6H_5) group : Benzene sulphonic acid when fused with NaCN, $NaNH_2$ and NaOH gives cyanobenzene, aniline and phenol, respectively. The formation of these compounds indicate that $-SO_3H$ group is directly attached to the benzene nucleus and in the formation of these compounds $-SO_3H$ group is replaced. Hence, the compound contains phenyl group and the compound may be represented as $C_6H_5SO_3H$.

(3) Presence of sulphonic acid ($-SO_3H$) group :

(i) Benzene sulphonic acid reacts with PCl_5 to form benzene sulphonyl chloride and HCl. This indicates that $-SO_3H$ group contains $-OH$ group similar to $-COOH$ group.

$$\underset{\text{Benzene sulphonic acid}}{C_6H_5SO_2OH} + PCl_5 \longrightarrow \underset{\text{Benzene sulphonyl chloride}}{C_6H_5SO_2Cl} + POCl_3 + HCl$$

(ii) The presence of acidic $-OH$ group is also indicated by the formation of salts with bases and formation of esters with alcohols.

$$\underset{\text{Benzene sulphonic acid}}{C_6H_5SO_2OH} + NaOH \longrightarrow \underset{\text{Sodiumbenzene sulphonate}}{C_6H_5SO_2ONa} + H_2O$$

$$C_6H_5SO_2OH + C_2H_5OH \xrightarrow{NaOH} \underset{\text{Ethylbenzene sulphonate}}{C_6H_5SO_2OC_2H_5} + H_2O$$

(iii) Benzene sulphonic acid on reduction with Zn and dil. H_2SO_4 gives thiophenol which on oxidation with alkaline $KMnO_4$ is again converted into benzene sulphonic acid. These reactions indicate that in benzene sulphonic acid, sulphur atom is directly attached to the benzene nucleus.

$$C_6H_5SO_3H + 6H \xrightarrow{Zn/H_2SO_4} \underset{\text{Thiophenol}}{C_6H_5SH} + 3H_2O$$

$$C_6H_5SH + 3O \xrightarrow[KMnO_4]{\text{Alkaline}} \underset{\text{Benzene sulphonic acid}}{C_6H_5SO_3H}$$

(4) Probable structure : On the basis of above facts, benzene sulphonic acid may be assigned the following structure :

$$C_6H_5-\underset{\underset{O}{\|}}{\overset{\overset{O}{\|}}{S}}-OH \quad \text{or} \quad C_6H_5-\underset{\underset{O}{\downarrow}}{\overset{\overset{O}{\uparrow}}{S}}-OH$$

[VIII] Uses of Sulphonation in Organic Chemistry

(i) In the preparation of a number of sulpha drugs such as sulpha pyridine, sulphadiazine, sulphathiazole, sulphaguanidine, chloramine–T.

(ii) In the preparation of saccharin which is 550 times sweeter than sugar.

(iii) In the manufacture of various dyes.

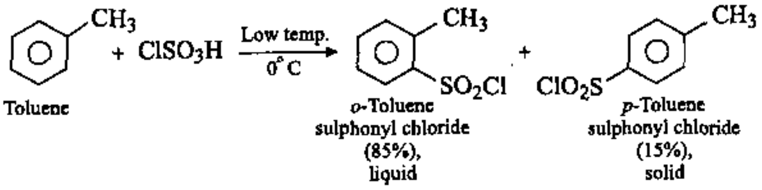
(iv) As a dehydrating agent in esterification, etherefication and other reactions.

(v) In the preparation of compounds like benzene, phenol, aniline, cyanobenzene, benzoic acid etc.

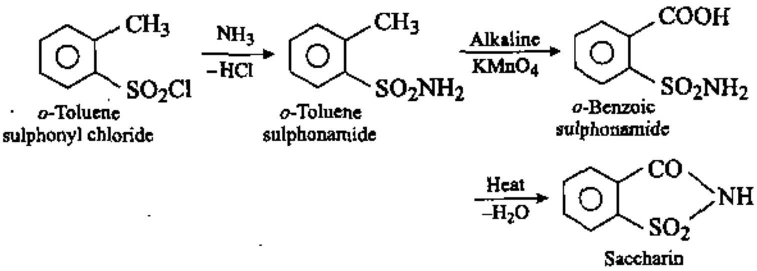
• 3.7. SACCHARIN

[I] Preparation

Toluene is sulphonated with chlorosulphonic acid at low temperature when a mixture of *o*- and *p*- toluene sulphonyl chlorides is obtained. The *o*-compound is obtained as the main product and *p*-compound is obtained in small amounts.



At low temperatures, the *o*-compound is liquid, whereas *p*-compound is solid, hence they are separated by filtration. From *o*-toluene sulphonyl chloride, saccharin is obtained as follows :



[II] Properties

Saccharin is a colourless, crystalline solid, M. Pt. 224°C. It is 550 times sweeter than sugar. It is insoluble in water and hence is sold as its sodium salt which is very soluble. It is very sweet in dilute solution but is bitter in concentrated solution.

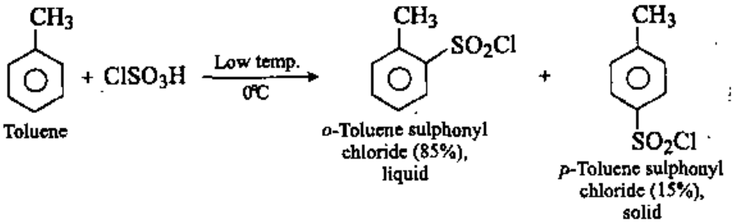
[III] Uses

Saccharin is used in cheap drinks in place of sugar. It is also used as a sweetening agent by diabetics and obese persons who are not allowed to use sugar in their diet.

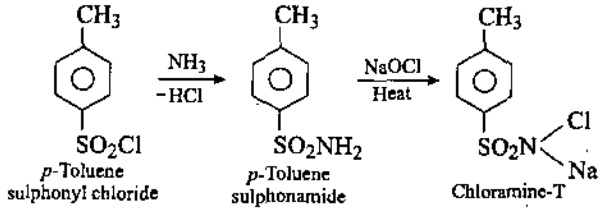
• 3.8. CHLORAMINE–T

[I] Preparation

From toluene : Toluene is sulphonated with chloro-sulphonic acid at low temperatures when a mixture of *o*- and *p*-toluene sulphonyl chlorides is obtained. The *o*-compound is obtained as the main product and *p*-compound is obtained in small amounts.



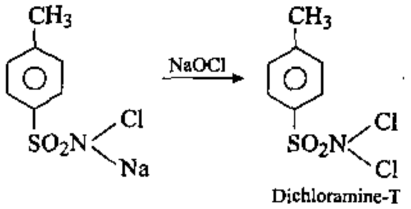
At low temperatures, the *o*-compound is liquid, whereas *p*-compound is solid, hence they are separated by filtration. From *p*-toluene sulphonyl chloride, chloramine–T is obtained as follows :



[II] Properties and Uses

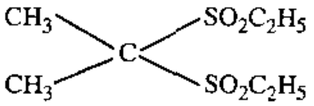
Chloramine-T is sufficiently stable when dry, but its aqueous solution is slowly hydrolysed to give hypochlorite ion, hence it is used as an antiseptic for wounds.

Chloramine-T reacts with sodium hypochlorite (NaOCl) to give dichloramine–T.



• SUMMARY

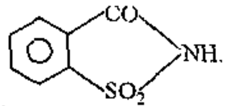
- Organometallic compounds are those compounds in which an organic group is attached through carbon to an atom which is less electronegative than carbon, *e.g.*, C_2H_5MgBr (ethyl magnesium bromide).
- The C—Mg bond in Grignard reagents is covalent but highly polar.
- Grignard reagents undergo substitution reactions.
- When sulphur atom is present in place of oxygen in an alcohol (R—OH), the corresponding alcohol is known as thiol (R—SH) or **mercaptan**. It is also known as thioalcohol.
- The IUPAC name of thioalcohol is thiol, *e.g.*, C_2H_5SH is known as ethanethiol.
- Sulphonal has the structure,

  It is used as a hypnotic, *i.e.*, sleep producing drug.
- The replacement of one or more hydrogen atoms of benzene nucleus by $-SO_3H$ groups is known as sulphonation.

$$C_6H_6 + H_2SO_4\ (\text{Conc.}) \xrightarrow{80^\circ C} C_6H_5\text{—}SO_3H + H_2O$$

- Saccharin has the structure

  It is 550 times more sweet than sugar.

• STUDENT ACTIVITY

1. How are Grignard's reagents prepared ?

2. Mention the preparation of saccharin.

3. Define sulphonation.

4. How is benzene sulphonic acid prepared in laboratory ? Give reaction also.

5. Write the structure of chloramine–T.

• TEST YOURSELF

1. What are organometallic compounds ?
2. What are Grignard's reagents ? How are they prepared ?
3. Give the synthetic importance of Grignard's reagents.
4. Starting from methyl magnesium iodide, how will you obtain the following compounds ?
(i) Propane (ii) Ethanoic acid (iii) Ethanol
(iv) Acetone (v) t-Butyl alcohol (vi) Methyl ethyl ketone
(vii) Diethylmercury (vii) Ethyl butyrate
5. What is the reaction of methyl magnesium iodide on ?
(i) Acetone (ii) Ethyl acetate (iii) Ethylene oxide
(iv) Ethyl cyanide (v) Acetamide (vi) Propionaldehyde
6. How will you obtain the following from Grignard's reagent ?
(i) Acetic acid (ii) n-Butyl alcohol (iii) Succinic acid (iv) Glutaric acid
(v) Ethanethiol (vi) Phenol
7. What are organolithium compounds ? Describe the preparation, properties and uses of organolithium compounds.
8. What are thiols ?
9. Describe the methods of preparation, properties and uses of thiols.
10. How is sulphonal prepared ?
11. Define sulphonation. Describe its mechanism.

12. How is benzene sulphonic acid prepared in the laboratory ?

13. Mention the important properties and structure of benzene sulphonic acid.

14. Starting from benzene sulphonic acid, how will you prepare the following compounds ?
(i) Benzene (ii) Phenol (iii) Thiophenol (iv) Aniline
(v) Benzamide (vi) Benzonitrile (viii) Benzoic acid

15. How is saccharin prepared ? Mention its uses.

16. Describe the preparation and properties of chloramine-T.

17. Which of the following is an organometallic compound ?
(a) C_2H_5ONa (b) $(C_2H_5)_4Pb$ (c) CH_3COONa (d) $Ti(OC_6H_5)_4$

18. Methyl magnesium iodide reacts with ethyl alcohol to give :
(a) CH_4 (b) C_2H_6 (c) C_3H_8 (d) None of these

19. Grignard reagent reacts with ethylene oxide to give a product which on hydrolysis gives :
(a) Primary alcohol (b) Secondary alcohol
(c) Tertiary alcohol (d) Alkene

20. Grignard reagent reacts with ethyl orthoformate to give a product which on hydrolysis gives:
(a) Primary alcohol (b) Secondary alcohol
(c) Aldehyde (d) Ketone

21. Grignard reagent reacts with CO_2 to give a product which on hydrolysis gives :
(a) Aldehyde (b) Ketone (c) Carboxylic acid (d) Ester

22. Methyllithium reacts with CO_2 to give a product which on hydrolysis gives :
(a) CH_3CHO (b) CH_3COCH_3 (c) CH_3COOH (d) CH_3COOCH_3

23. Chemically mercaptans belong to the class :
(a) Aldehydes (b) Ketones (c) Alcohols (d) Thioalcohols

24. The sulphonation of benzene is :
(a) Nucleophilic substitution (b) Electrophilic substitution
(c) Nucleophilic addition (d) Electrophilic addition

25. The active species in the aromatic sulphonation is :
(a) H_2SO_3 (b) HSO_3^- (c) SO_4^{2-} (d) SO_3H^+

26. Fill in the blanks :
(i) Organometallic compounds are defined as those which contain one or more .... bonds.
(ii) Grignard reagent is an organo .... compound.
(iii) Chemically Hinsberg reagent is ....
(iv) Chloramine-T is used as an ....

ANSWERS

17. (b) **18.** (a) **19.** (a) **20.** (c) **21.** (c) **22.** (b) **23.** (d) **24.** (b) **25.** (b)
26. **(i)** metal-carbon **(ii)** magnesium **(iii)** benzene sulphonyl chloride **(iv)** antiseptic.

❑❑❑

UNIT

4

POLYNUCLEAR HYDROCARBONS AND HETEROCYCLIC COMPOUNDS

LEARNING OBJECTIVES

- Naphthalene
- Anthracene
- Heterocyclic Compounds
- Pyrrole
- Thiophene
- Furan
- Pyridine
- Indole
- Quinoline
- Isoquinoline

❑ Summary
❑ Student Activity
❑ Test Yourself

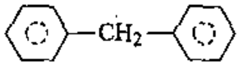
AROMATIC POLYNUCLEAR HYDROCARBONS

Introduction

Polynuclear hydrocarbons contain more than one aromatic rings. They are of two types :

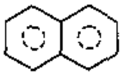
(1) Isolated polynuclear hydrocarbons : These are compounds in which the rings are isolated, *i.e.*, benzene nuclei are either linked directly to each other or through one or more carbon atoms, *e.g.*, diphenyl, diphenyl methane, etc.

Diphenyl

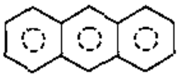


Diphenyl methane

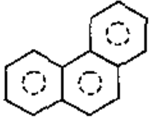
(2) Fused polynuclear hydrocarbons : In these compounds, the aromatic rings are fused due to the sharing of two or more carbon atoms by two or more rings, e.g., naphthalene, anthracene, phenanthrene, etc.



Naphthalene



Anthracene



Phenanthrene

• 4.1. NAPHTHALENE

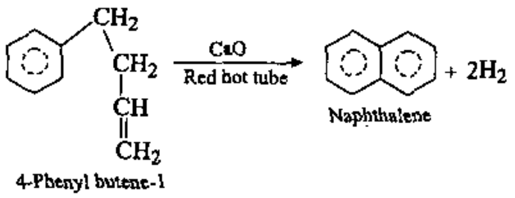
Naphthalene *is the simplest condensed polynuclear hydrocarbon in which two benzene rings* are fused in ortho positions. It occurs in coal tar to an extent of 6%. It is isolated from middle oil fraction.

[I] Manufacture of Naphthalene

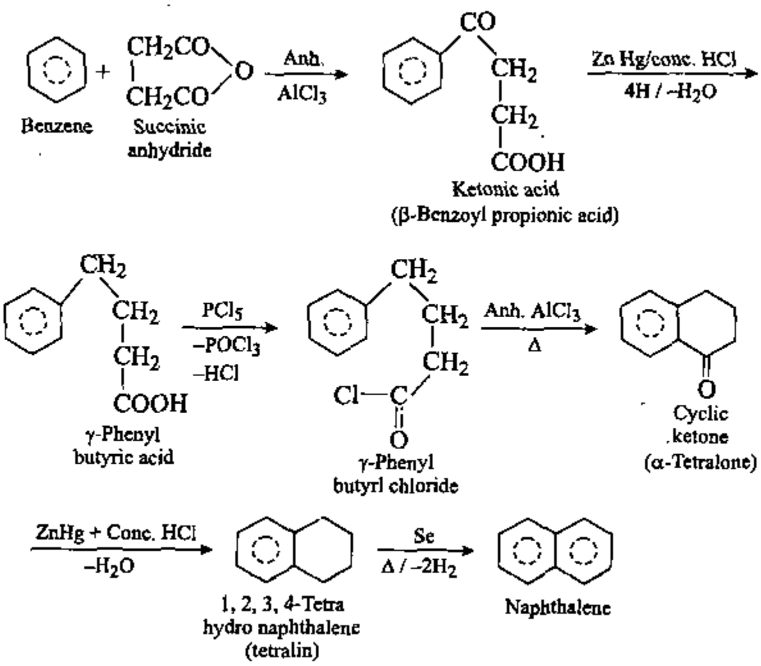
(1) Isolation from coal tar : Naphthalene is prepared from middle oil fraction of coal tar. This fraction is chilled when naphthalene crystallises out. The crude naphthalene is separated by pressing or centrifuging. The solid mass so obtained is washed with hot water and aqueous alkali to remove traces of oils and phenols. It is then washed with *dilute* H_2SO_4 *to remove basic impurities.* Finally, it is purified by sublimation.

[II] Synthetic Methods

(a) From 4-phenyl butene-1 :

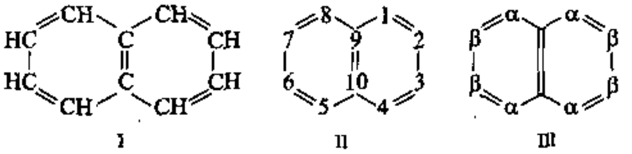


(b) Haworth's synthesis :



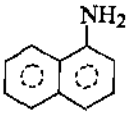
[III] Nomenclature of Naphthalene

Naphthalene is represented in either of the following ways :

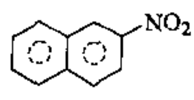


Positions in the naphthalene ring system are shown either by numbering the different positions or by designating them with Greek letters α and β. Positions 1, 4, 5 and 8 are same and are designated as α-positions, while positions 2, 3, 6 and 7 are same and are designated as β-positions.

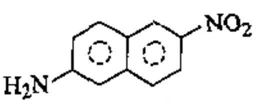
Naphthalene forms two mono-substituted derivatives, *e.g.*, two naphthols, two chloronaphthalenes, etc. For naming monosubstituted naphthalenes, the prefixes 1- and 2- or α- and β- are used, but in case of more highly substituted naphthalenes, the positions of the groups are shown by numbers, *e.g.*,



1-Aminonaphthalene
or α-Aminonaphthalene



2-Nitronaphthalene
or β-Nitronaphthalene



6-Amino 2-nitro
naphthalene

There are 10 isomeric disubstitution products when both the substituents are same. For example, when two hydrogen atoms of naphthalene are replaced by two chlorine atoms, the following ten dichloro naphthalenes are possible—1 : 2, 1 : 3, 1 : 4, 1 : 5, 1 : 6, 1 : 7, 1 : 8, 2 : 3, 2 : 6, 2 : 7.

[III] Physical Properties

Naphthalene is a colourless crystalline solid, M.P. 80°C. It is insoluble in water, but soluble in ether, benzene etc. It has a characteristic *'moth ball'* odour. It sublimes readily when heated and is volatile in steam.

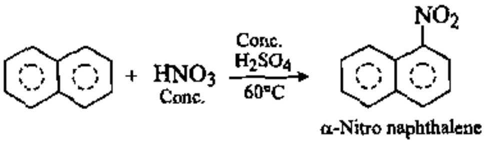
[IV] Chemical Properties

Chemically, naphthalene resembles benzene in many of its reactions, though it is more reactive.

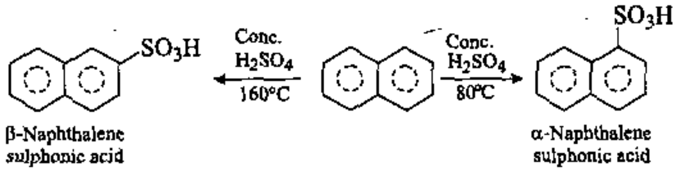
(A) Electrophilic Substitution Reactions

Naphthalene undergoes electrophilic substitution reactions, substitution occurs primarily at C–1 (α-position). Substitution at C–2 (β-position) occurs only when the reactions are carried out at higher temperatures or when bulkier solvents are used.

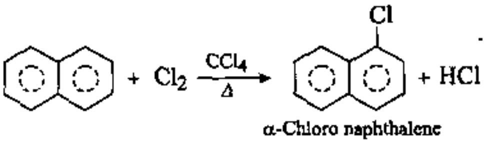
(1) Nitration : Naphthalene undergoes nitration with conc. HNO_3 in presence of sulphuric acid at 60° to form α-nitro naphthalene.



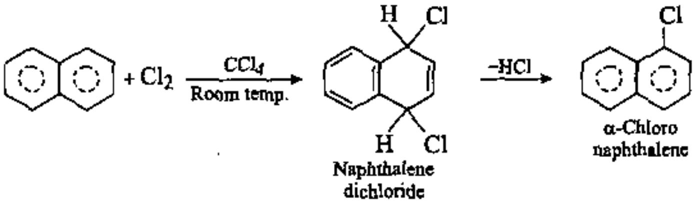
(2) Sulphonation : Naphthalene undergoes sulphonation with conc. sulphuric acid at 80°C to form α-naphthalene sulphonic acid. At 160°C, β-naphthalene sulphonic acid is formed.



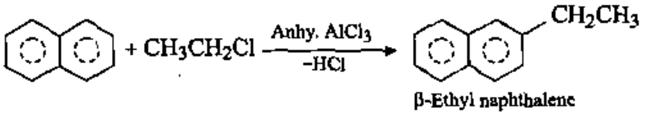
(3) Halogenation : Naphthalene shows chlorination or bromination in boiling CCl_4 to form α-chloro naphthalene.



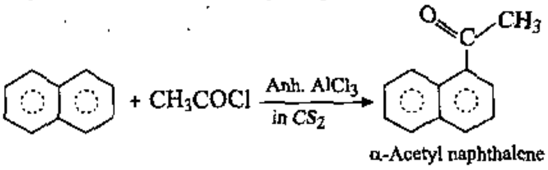
At room temperature, naphthalene dichloride is formed, which on heating gives α-chloro naphthalene.



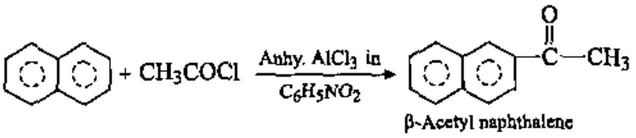
(4) Friedel-Crafts alkylation : Alkyl halides (except methyl halides) react with naphthalene in presence of anhydrous $AlCl_3$ to form β-alkyl naphthalene.



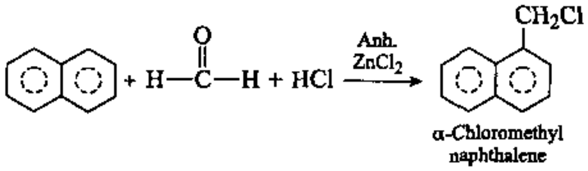
(5) Friedel-Crafts acylation : With acetyl chloride and anhydrous $AlCl_3$ in carbon disulphide, naphthalene undergoes acylation to form α-acetyl naphthalene.



When nitrobenzene is used as a solvent, β-acetyl naphthalene is formed.

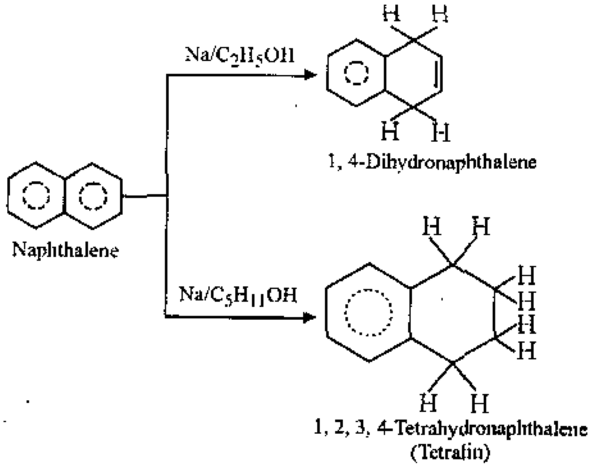


(6) Chloromethylation : Naphthalene reacts with HCHO and HCl in presence of Anh. zinc chloride to form α-chloromethyl naphthalene.

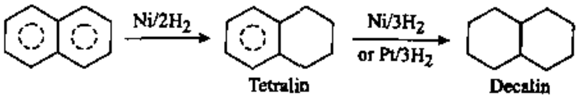


(B) Other Reactions

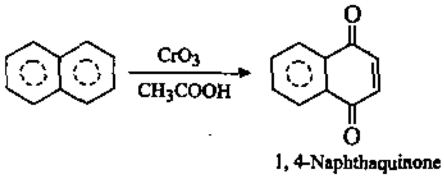
(1) Reduction : Naphthalene undergoes reduction more easily than benzene. With sodium and ethyl alcohol, naphthalene forms 1, 4-dihydronaphthalene, but with sodium and isoamyl alcohol, it gives 1, 2, 3, 4-tetrahydronaphthalene (tetralin).



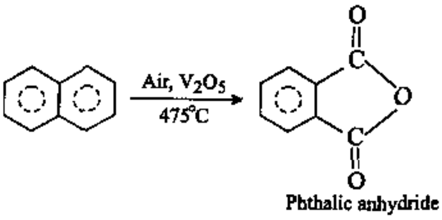
Tetralin is also obtained by the catalytic hydrogenation of naphthalene. On further hydrogenation, tetralin forms decalin.



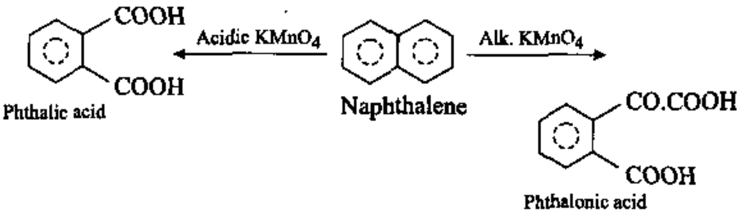
(2) Oxidation : (a) Naphthalene is easily oxidised, (a) With CrO_3 in acetic acid at room temperature, it oxidises to form 1, 4-naphthaquinone.



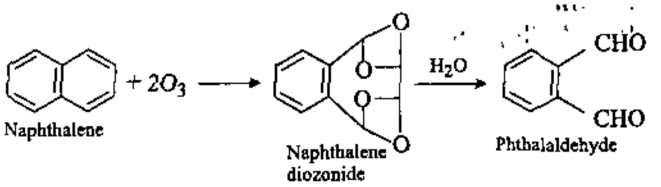
(b) With oxygen and V_2O_5 at 475°C, naphthalene is oxidised to form phthalic anhydride.



(c) In acidic medium, $KMnO_4$ oxidises naphthalene to form phthalic acid, while in alkaline medium, it forms phthalonic acid.



(d) With ozone, naphthalene first forms diozonide which on hydrolysis gives phthalaldehyde.



[V] Uses

Naphthalene is used as 'moth balls' to protect woollen clothes from moths. It is also used in increasing the illuminating power of coal gas. It is used in the manufacture of phthalic anhydride, 2-naphthol, dyes, carbaryl for insecticides and several medicinal products.

[VI] *Constitution*

(1) Elemental analysis and molecular weight determination shows that naphthalene has the molecular formula $C_{10}H_8$.

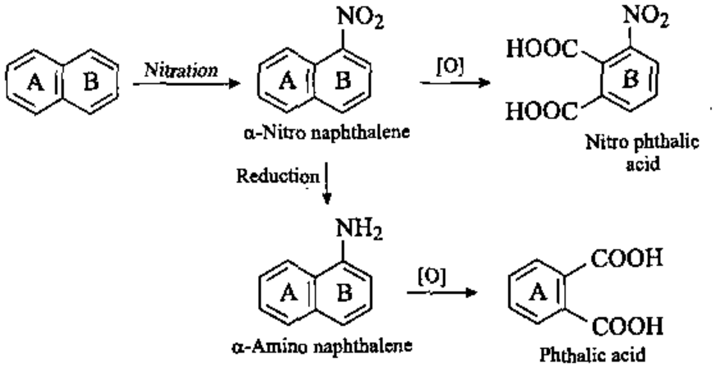
(2) Like benzene, it is resistant to addition reactions though less than benzene. It undergoes electrophilic substitution reactions *like halogenation, nitration, sulphonation.*

(3) Naphthalene on oxidation gives phthalic acid. This shows that it contains a benzene ring with two ortho side chains.

(4) Benzene shows aromatic behaviour. Graebe showed that at least one benzene ring is present in naphthalene and *there may be two side chains in ortho positions to one another.*

(5) Erlenmeyer suggested that naphthalene contains two benzene rings fused in ortho positions. This fact was also confirmed by Graebe.

This fact can be confirmed as naphthalene gives α-nitro naphthalene on nitration, which on oxidation gives nitro phthalic acid. If nitro naphthalene is reduced to amino naphthalene and then oxidised, then only phthalic acid is formed in place of amino phthalic acid. These reactions can only be explained if it is assumed that naphthalene has two benzene rings A and B fused in ortho position.



In the first case —NO_2 group is meta directing and hence it reduces the reactivity of ring *B*. Therefore ring *A* is more reactive and hence it is oxidized. In the second case, —NH_2 group is *o*-and *p*-directing and therefore it increases the reactivity of ring *B* and hence it is oxidized.

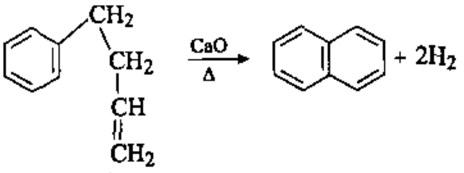
(1) Evidences in Favour of Erlenmeyer's Formula

(a) Erlenmeyer's formula shows the presence of five double bonds in the molecule and naphthalene is known to add a maximum of five molecules of hydrogen to form decalin.

(b) This formula suggests the formation of two mono substituted derivatives and ten disubstituted derivatives, which is in agreement with the known facts.

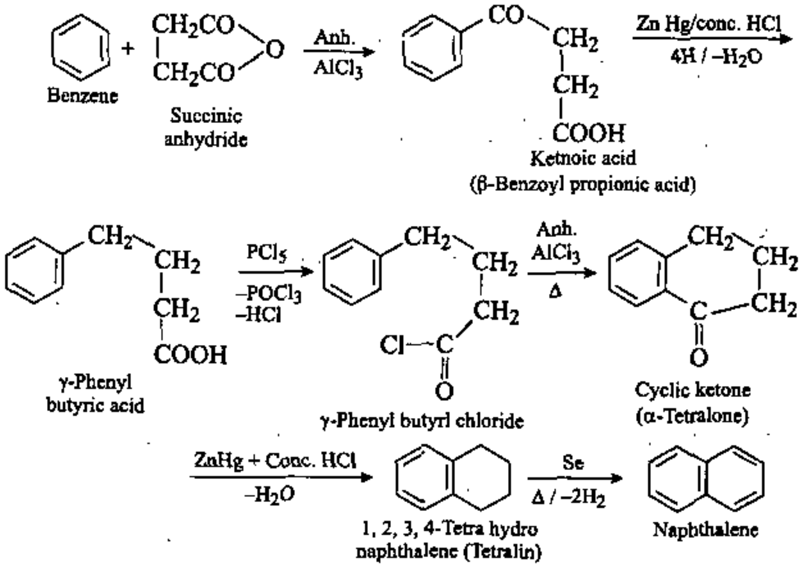
(c) ***Synthesis of naphthalene :*** Erlenmeyer's formula has been supported by several methods of synthesis of naphthalene.

(i) If 4-phenyl butene-1 is passed over red hot calcium oxide, naphthalene is obtained.



4-Phenyl butene-1

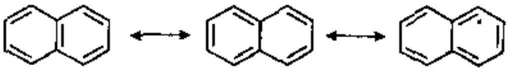
(ii) ***Haworth's synthesis :*** Friedel-Crafts reaction of succinic anhydride with benzene in presence of anhydrous $AlCl_3$ gives a ketonic acid (I), which is reduced to (II). This on cyclisation gives ketone (III), which on reduction gives tetralin (IV). Tetralin when dehydrogenated forms naphthalene.



(2) Present Day Position

Physico-chemical studies of naphthalene show that (i) all C and H atoms in naphthalene lie in the same plane and (ii) the value of heats of combustion and hydrogenation for naphthalene is much lower than that calculated for Erlenmeyer's formula. So, the structure of naphthalene can be explained on the basis of the following concepts.

(1) Resonance concept : Naphthalene is considered to be resonance hybrid of various contributing forms.



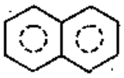
It is supported by the following facts :

(a) Naphthalene is a planar molecule.

(b) X-ray studies have shown that all C—C bonds in naphthalene are not equivalent, C_1—C_2 bond (1.36Å) is much shorter than C_2—C_3 bond (1.40 Å). In other words, the C_1—C_2 bond has a relatively greater double bond character than the C_2—C_3 bond. This may be due to the fact that C_1—C_2 bond is double in two contributing forms, but single in one, whereas C_1—C_2 bond is single in two structures but double in only one.

(2) Molecular orbital concept : All the carbon atoms in naphthalene are in sp^2 hybridised state and lie at the corners of two fused hexagons. Each of the carbon atom is attached to two other carbon atoms and one hydrogen by σ bonds formed by overlapping of trigonal sp^2 hybrid orbitals. Consequently, all ten carbons and eight hydrogens lie in one plane. Naphthalene contains $10\,\pi$ electrons, which is in accordance with Huckel $(4n + 2)$ rule of aromaticity. So, naphthalene should be a true aromatic compound. This is, however, so as evident from the chemical behaviour of naphthalene.

Thus, the structure of aromatic compound naphthalene with two benzene rings fused in ortho positions is established and is represented as :

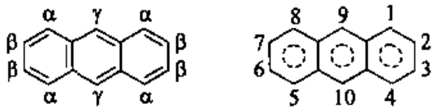


• 4.2. ANTHRACENE

Anthracene occurs in coal tar distillation fraction known as anthracene oil or green oil, because of its dark green fluoresence. It is collected between 270°–360°C and contains phenanthrene and carbazole, besides 10% anthracene.

[I] Nomenclature and Isomerism of Anthracene

The positions of different carbon atoms in anthracene are shown by numbers of Greek letters as shown :



Thus, it is evident that in anthracene, three different positions are available for a substituent and so it gives 3 isomeric monosubstitution products, *viz*., α- or 1-; β- or 2- and γ- or 9- (or meso). When the two substituents are identical, 15 isomers are possible. However, when the two substituents are not identical, large number of isomers are possible.

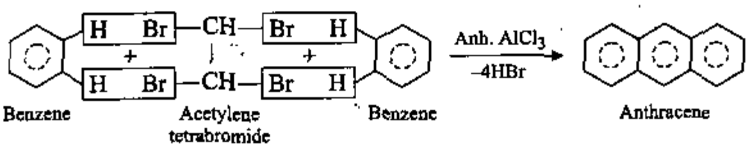
[II] Preparation of Anthracene (From anthracene oil)

Anthracene oil is cooled and allowed to crystallise for nearly a week. It is filtered and the solid known as anthracene cake is pressed to make it free from liquid. The cake is powdered and first washed with solvent naphtha to dissolve phenanthrene and then with pyridine to remove carbazole by dissolving it. The solid left behind is crude anthracene, which is purified by sublimation.

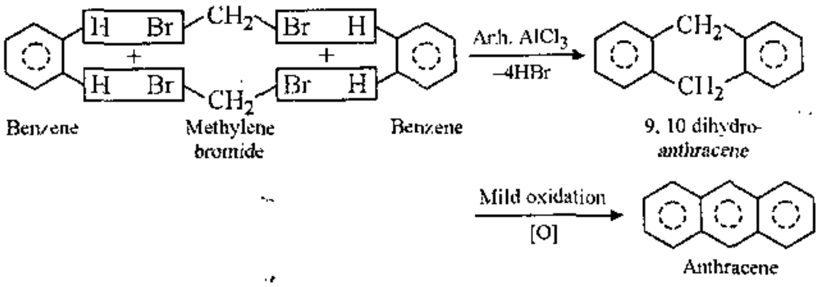
Synthesis of Anthracene

[1] From benzene

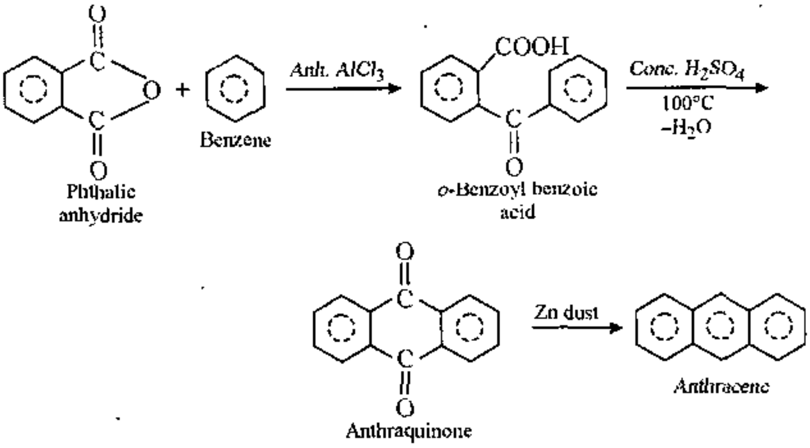
(a) By the condensation of benzene with acetylene tetrabromide in presence of anhydrous $AlCl_3$.



(b) By the condensation of benzene with methylene bromide in presence of Anhydrous $AlCl_3$, 9 : 10 dihydroanthracene is obtained which on mild oxidation gives anthracene.

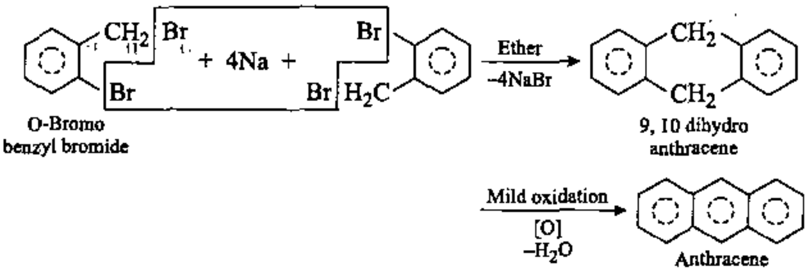


(c) By the condensation of benzene with phthalic anhydride in presence of Anhydrous $AlCl_3$, *o*-benzoyl benzoic acid is obtained. This on heating with conc. H_2SO_4 at 100°C forms anthraquinone which on distillation with Zn dust gives anthracene.



(2) From o-bromo benzyl bromide

By heating *o*-bromobenzyl bromide with sodium in presence of ether, 9 : 10 dihydroanthracene is obtained which on mild oxidation gives anthracene.



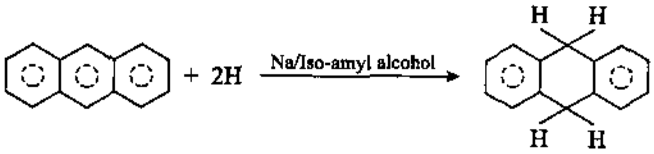
[III] Physical Properties

Anthracene is a colourless solid, M.P. 216°C, showing a blue fluorescence. It is insoluble in water, sparingly soluble in organic solvents, but fairly soluble in hot benzene.

[IV] Chemical Properties

Anthracene resembles benzene and naphthalene in many respects. The positions 9- and 10- are very reactive. To account for the reactivity of these positions, it has been suggested that anthracene is in equilibrium with a free diradical. Some of the important reactions of this ring system are :

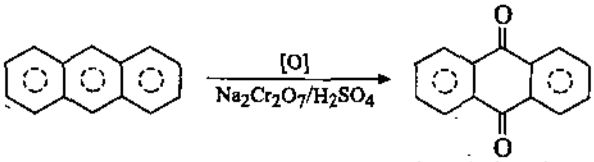
(1) Reduction : When reduced with sodium and iso-amyl alcohol, anthracene forms 9, 10-dihydroanthracene.



9, 10-Dihydroanthracene

Catalytic hydrogenation (Ni/H_2) forms tetra, hexa and octahydroanthracenes depending on the amount of hydrogen present. Finally, it forms per-hydroanthracene, $C_{14}H_{24}$.

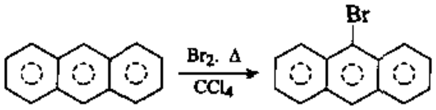
(2) Oxidation : Anthracene is readily oxidised by chromic acid to give 9, 10-anthraquinone.



9, 10-Anthraquinone

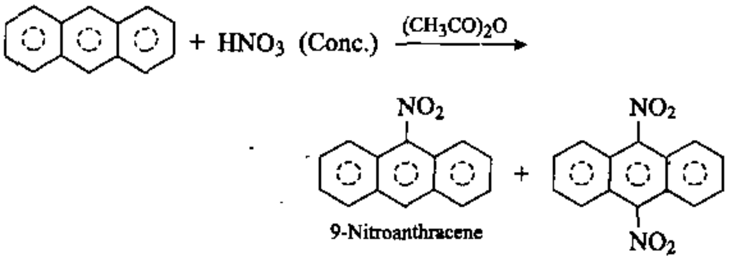
(3) Electrophilic substitution reactions : Anthracene undergoes electrophilic substitution reactions, *e.g.*, halogenation, nitration, sulphonation, acetylation etc. as shown below :

(a) Halogenation



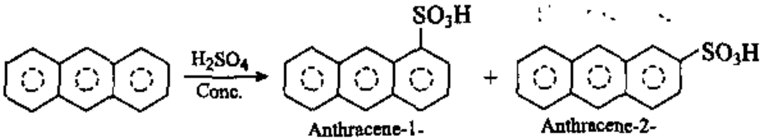
9-Bromoanthracene

(b) Nitration



9, 10-Dinitroanthracene

(c) Sulphonation

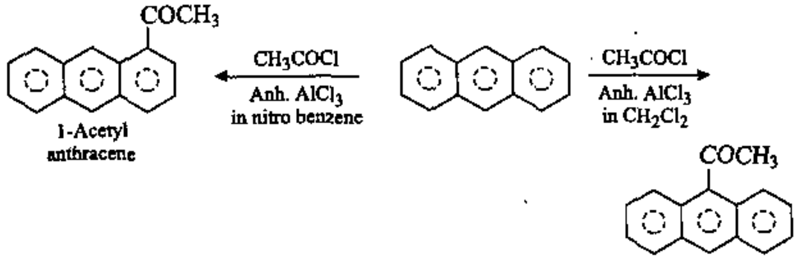


Anthracene-1-sulphonic acid

Anthracene-2-sulphonic acid

At higher temperatures, anthracene 2-sulphonic acid is the main product.

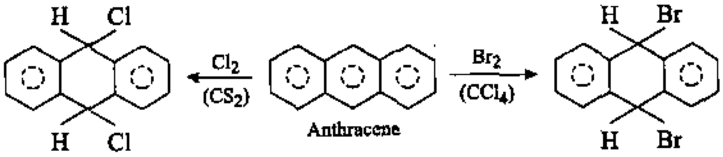
(iv) Acetylation



1-Acetyl anthracene

9-Acetyl anthracene

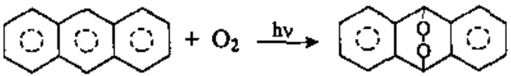
(4) Electrophilic addition reactions : Though anthracene is an aromatic compound, yet it is relatively more unsaturated than benzene or naphthalene. It adds halogens at ordinary temperatures. Addition occurs preferably at 9- and 10 positions, *e.g.*,



Anthracene 9, 10 dichloride

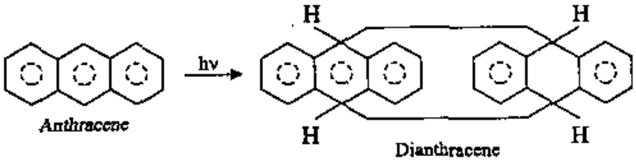
Anthracene 9, 10 dibromide

(5) In presence of light, anthracene adds a molecule of oxygen to form anthracene peroxide.



Anthracene peroxide

(6) Dimerisation : Anthrance dimerises to dianthracene or para-anthracene when a xylene solution of anthracene is exposed to light.



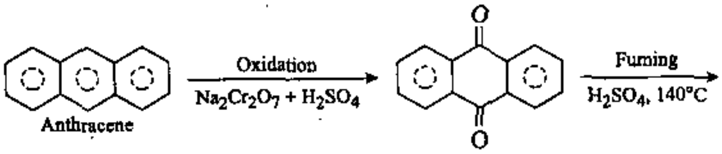
Dianthracene

(7) Picrate formation : Anthracene forms a red coloured picrate (M.P. 138°C) with picric acid.

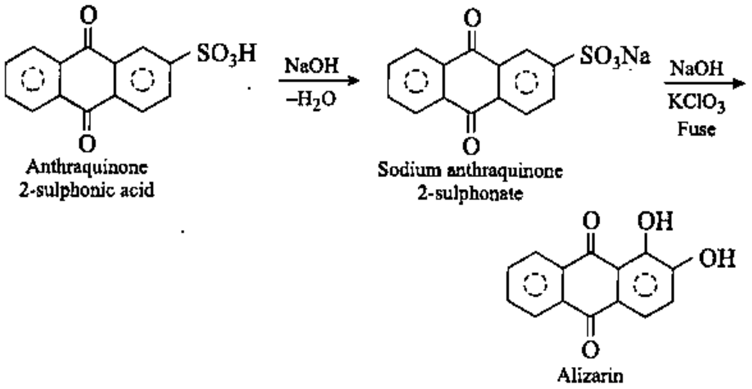
$$\underset{\text{Anthracene}}{C_{14}H_{10}} + \underset{\text{Picric acid}}{C_6H_2(NO_2)_3(OH)} \longrightarrow \underset{\text{Anthracene picrate}}{C_{14}H_{10} \cdot C_6H_2(NO_2)_3(OH)}$$

(8) Reaction with sodium : Anthracene reacts with sodium to form a deep coloured disodium salt, 9, 10-disodioanthracene.

(9) Formation of alizarin : Anthracene forms alizarin (dye) as follows :



9, 10 Anthraquinone



[III] Uses

Anthracene is used in the :

(i) Preparation of anthraquinone dyes, *e.g.*, alizarin.
(ii) Manufacture of anthraquinone.
(iii) Making of smoke screens.

• 4.3. HETEROCYCLIC COMPOUNDS

[I] Heterocyclic Compounds

Heterocyclic compounds are defined as the *cyclic compounds which have hetero atom(s) at one or more corners of the ring in addition to carbon atoms.* These other elements or hetero atoms are oxygen, sulphur and nitrogen. A heterocyclic compound may or may not be aromatic in nature.

The most stable heterocyclic compounds are those having five or six-membered rings. So, heterocyclic compounds can be defined as *five or six-membered cyclic compounds, with at least one hetero atom as the ring member, which are relatively stable and show aromatic character.* Alkaloids, dyes, drugs, enzymes, proteins are important members of this group.

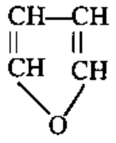
[II] Characteristics of Heterocyclic Compounds

(i) They show aromatic properties similar to benzene.
(ii) They are highly stable.
(iii) They contain conjugated double bonds.

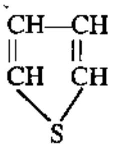
[III] Classification of Heterocyclic Compounds

Heterocyclic compounds can be divided into two classes. These are :

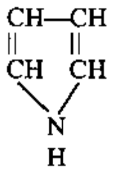
(1) *Five-membered heterocyclics* : These are derived from benzene by the replacement of a C $=$ C bond by a hetero atom with an unshared electron pair.



Furan
(Oxole)



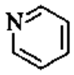
Thiophene
(Thiole)



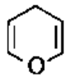
Pyrrole
(Azole)

(2) *Six-membered heterocyclics* : In this, carbon of benzene is replaced by an isoelectronic hetero atom to yield six-membered heterocyclics, *e.g.*, pyridine, pyrimidine etc.

Pyridine

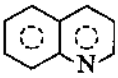


Pyrimidine

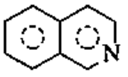


γ-Pyran

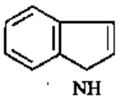
(3) Condensed heterocyclics : These may consist of two or more fused rings which may be partly carbocyclic and partly heterocyclic, *e.g.*,



Quinoline



Isoquinoline



Indole

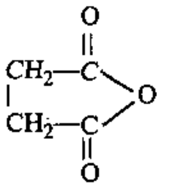
Some of the hetero cyclic rings such as ethylene oxide, γ-and δ- lactones are not considered as heterocyclic compounds because :

(i) These compounds do not exhibit aromatic properties like sulphonation, nitration etc.

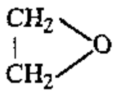
(ii) These compounds are not very stable. Their rings may be opened very easily.

(iii) These compounds do not contain conjugated double bonds.

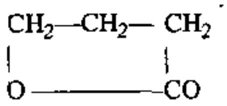
Aliphatic compounds, which look like heterocyclics but may not be regarded as heterocyclics, are :



Succinic anhydride



Ethylene oxide



γ Butyro lactone

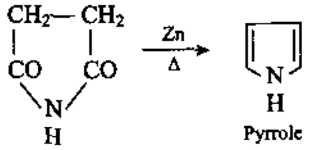
• 4.4. PYRROLE

[I] Preparation

(1) ***Isolation from bone oil*** : Bone oil is obtained by the dry distillation or pyrolysis of animal by-products, *e.g.*, bones, horns, hooves, etc. Pyrrole can be isolated from bone oil, by washing the latter with dilute sulphuric acid to remove the basic substances. Then it is washed with dilute alkali to remove acidic substances and is finally subjected to fractional distillation. The fraction between 100° and 150°C contains pyrrole, which can be removed by boiling with potassium hydroxide. On steam distilling of the potassium salt so formed we get pyrrole, which is purified by distillation.

$$\underset{\text{Potassio pyrrole}}{C_4H_4NK} + H_2O \xrightarrow[\text{distillation}]{\text{Steam}} \underset{\text{Pyrrole}}{C_4H_4NH} + KOH$$

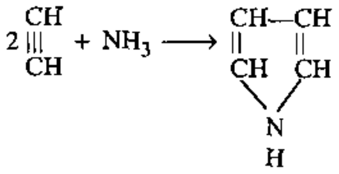
(2) Distillation of succinimide with zinc dust gives pyrrole.



Succinimide

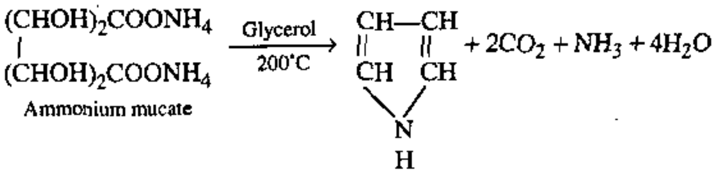
Pyrrole

(3) Pyrrole can be obtained by passing a mixture of acetylene and ammonia through a red hot tube.



Pyrrole

(4) Pyrrole is obtained by distilling a mixture of ammonium mucate and glycerol at 200°C.

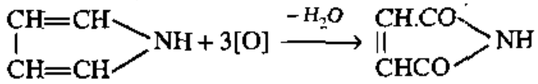


Ammonium mucate

[II] Resemblance With Aromatic Compounds

(i) Like benzene, pyrrole has a sextet and so exhibits the aromatic properties like stability and ability to form substitution products.

(ii) Pyrrole on oxidation forms maleic imide. Benzene also forms maleic anhydride.

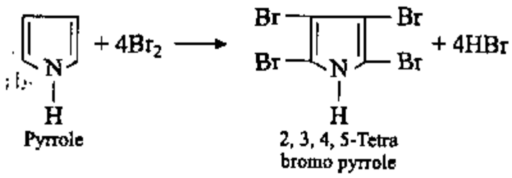


Pyrrole

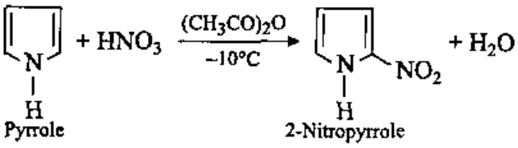
Maleic imide

(iii) It shows aromatic substitution reactions. The substitution mainly takes place at α-positions (2 and 5) because of high electron density as shown below.

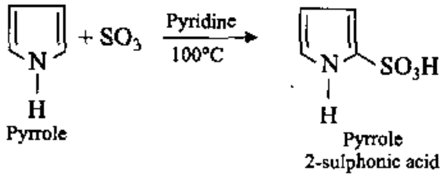
(a) Halogenation



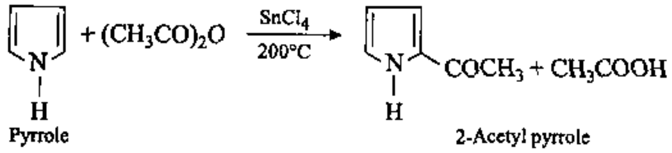
(b) Nitration



(c) Sulphonation

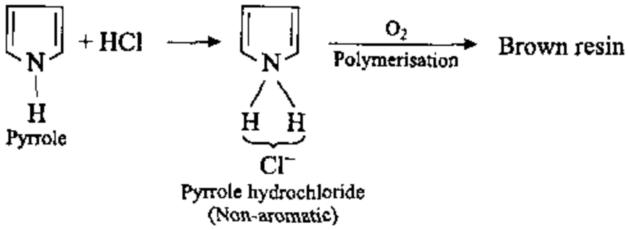


(d) Acetylation

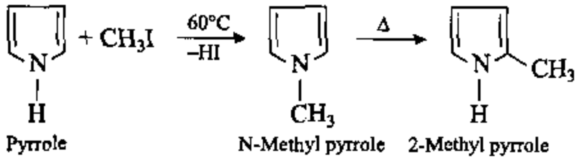


[III] Resemblance with Aromatic Amines

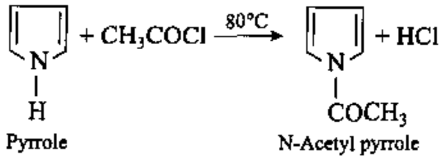
(i) Basic nature : The N atom in pyrrole contributes its lone pair of electron in the ring to form a $(4n + 2)$ π electron system. Thus, the availability of lone pair of electrons on nitrogen atom decreases for protonation. Therefore, pyrrole is a weak base ($pK_a = 3.4$). It reacts with dilute hydrochloric acid to form a crystalline hydrochloride, which is stable in absence of oxygen, otherwise polymerisation occurs rapidly to form a brown resin.



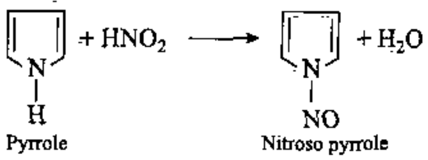
(ii) Alkylation : Pyrrole reacts with methyl iodide at 60°C to form N-methyl pyrrole which on heating rearranges to give 2-methyl pyrrole.



(iii) Acetylation : Pyrrole reacts with acetyl chloride at 80°C to form N-acetyl pyrrole.

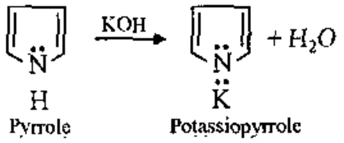


(iv) Action with HNO_2 : Pyrrole reacts with HNO_2 to give nitroso pyrrole which indicates the presence of secondary amino group.



[IV] Resemblance with Phenols

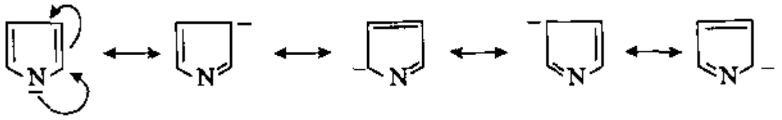
(1) Acidic nature : Pyrrole exhibits weakly acidic nature ($K_a = 10^{-15}$) and forms alkali metal salts, *e.g.*,



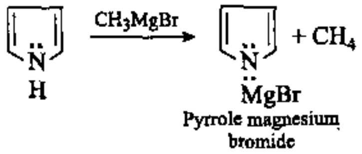
The acidic character of pyrrole is due to two reasons :

(i) The relatively easy dissociation of proton attached to nitrogen atom.

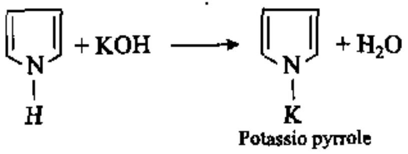
(ii) The greater stability of the pyrrole anion as compared to pyrrole.



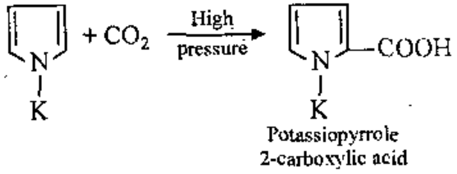
Pyrrole also reacts with Grignard reagents to form salt-like N-magnesium halides, which also points to its acidic character.



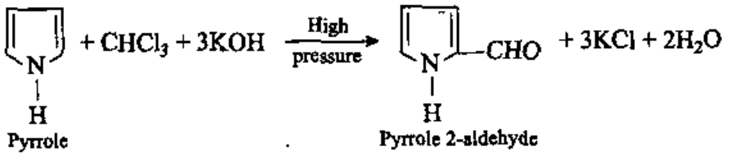
Pyrrole also reacts with solid NaOH or solid KOH to give sodio or potassio pyrrole.



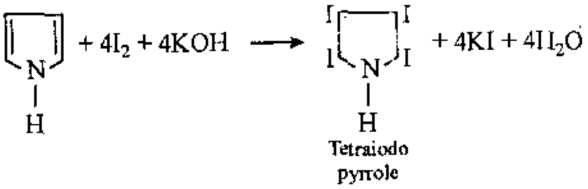
(ii) Kolbe Schmidt reaction : Potassium pyrrole reacts with CO_2 at high pressure to give potassiopyrrole 2-carboxylic acid.



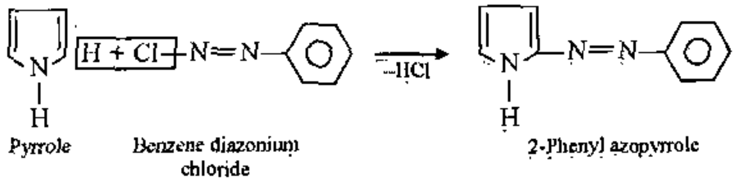
(iii) Reimer Tiemann reaction : *Pyrrole reacts with $CHCl_3$ and KOH to give pyrrole* 2-aldehyde.



(iv) Reaction with iodine : Pyrrole reacts with iodine in presence of alkalies to form tetraiodo pyrrole.

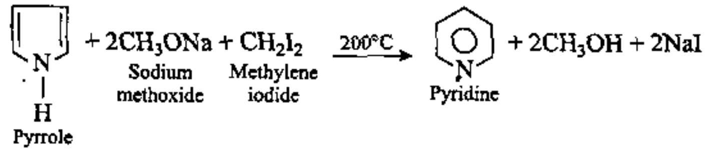


(v) Coupling reaction : Pyrrole reacts with benzene diazonium chloride to form 2-phenyl azopyrrole

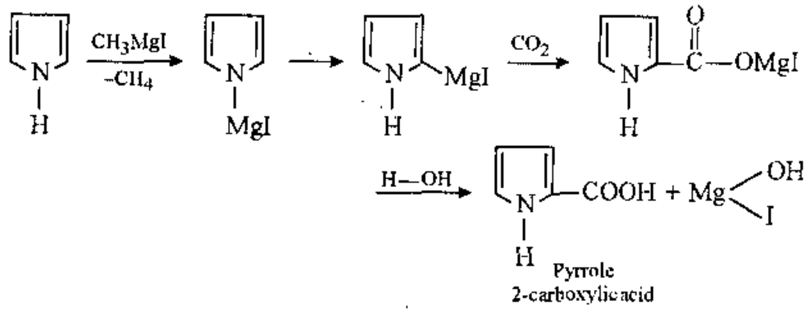


[V] Conversions of Pyrrole

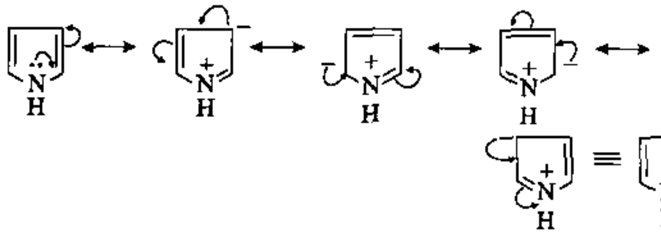
(i) Pyridine



(ii) Pyrrole 2-carboxylic acid



[V] Resonating Forms of Pyrrole



• 4.5. THIOPHENE

Thiophene is present in coal tar and is distilled in the benzene fraction.

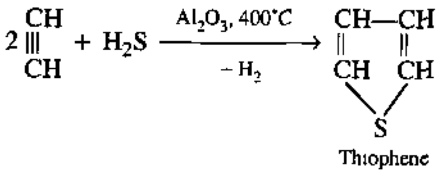
[I] Preparation

(1) From coal tar : Benzene obtained from coal tar contains thiophene. It is treated with cold concentrated sulphuric acid, when thiophene is sulphonated more readily than benzene. Thiophene sulphonic acid is soluble in water and is removed on extraction with water. Thiophene sulphonic acid is treated with superheated steam to obtain thiophene.

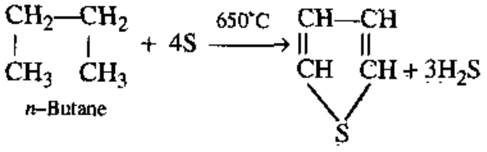
A better method is to reflux the mixture of benzene and thiophene with aqueous mercuric acetate. Thiophene is mercurated, while benzene remains unaffected. Separation of mercurated derivative and its distillation with hydrochloric acid gives thiophene.

(2) Manufacture :

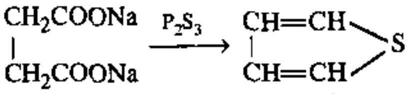
(a) Thiophene is manufactured by passing a mixture of acetylene and hydrogen sulphide through a tube containing Al_2O_3 at 400°C.



(b) At present, it is obtained commercially by reaction between *n*-butane and sulphur in vapour phase.



(3) Laboratory method : Thiophene can be obtained by heating sodium succinate with phosphorus trisulphide.



Thiophene

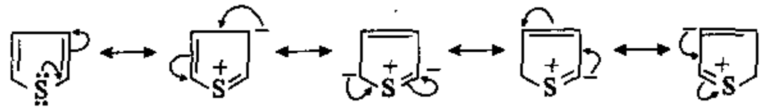
[II] Physical Properties

Thiophene is a colourless liquid, B.P. = 84°C. It is insoluble in water but soluble in organic solvents.

[III] Chemical Properties

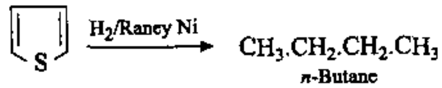
Chemically, thiophene resembles benzene rather closely in most of its chemical reactions. The resemblance is due to almost similar molecular weight, similar shapes of the molecules and similar electronic structures. As compared to furan and pyrrole, it is comparatively more stable.

Thiophene is aromatic in nature and is a resonance hybrid of the following structures :

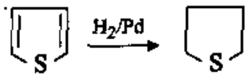


Some important reactions of thiophene are as follows :

(1) Addition reactions : Thiophene is catalytically reduced to tetrahydrothiophene *(thiophan or thiolan).* Catalytic reduction with hydrogen with Raney nickel (catalyst) forms *n*-butane, *i.e.*, results in the removal of sulphur.



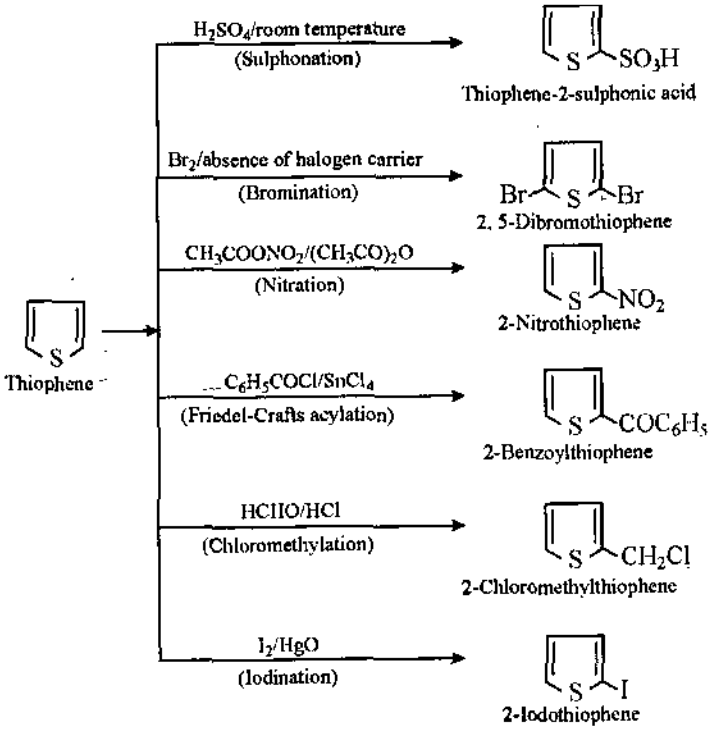
n-Butane



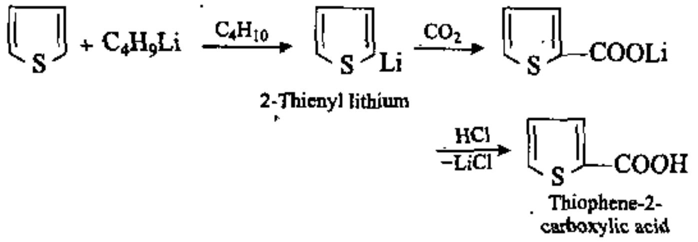
Tetrahydro-thiophene

(2) Oxidation : Thiophene cannot be oxidised to sulphoxides or sulphones, as it does not *form sulphonium salts.* Reactions with H_2O_2 opens the ring and sulphur is oxidised to sulphuric acid.

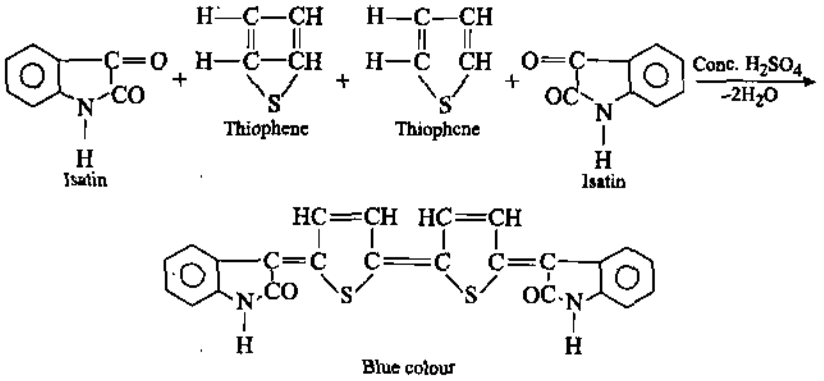
(3) Electrophilic substitution reactions : Thiophene undergoes electrophilic substitution reactions primarily at C—2 or C—5. Substitution at C—3 or C—4 occurs only when both C—2 and C—5 positions are occupied. The important substitution reactions are mentioned below :



(4) Reactions with organometallic compounds : Thiophene reacts with butyllithium to give 2-thienyl lithium, which reacts with CO_2 followed by HCl to give thiophene-2-carboxylic acid.



(5) On treating thiophene with isatin and conc. H_2SO_4, a blue colour is obtained (***Indophenin reaction***).

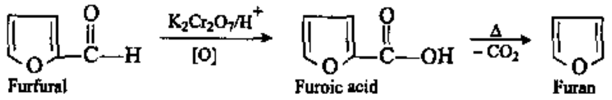


• 4.6. FURAN

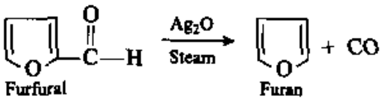
[I] Preparation

(1) Furan is obtained by the distillation of wood, especially pine-wood.

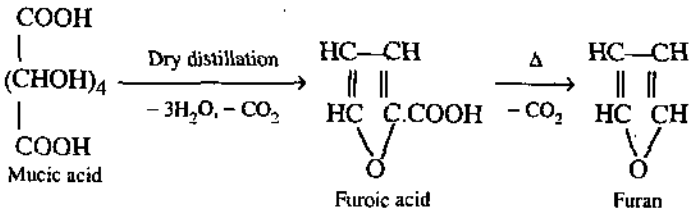
(2) Furan can be obtained by oxidation of furfural with $K_2Cr_2O_7$ and dil. H_2SO_4 to give furoic acid and subsequent decarboxylation at 200–300°C.



(3) Furan is obtained by decarboxylation of furfural in steam in presence of silver oxide (catalyst) *[Commercial method]*.



(4) Furan is obtained by dry distillation of mucic acid and heating the product, furoic acid at 200°–300°C.

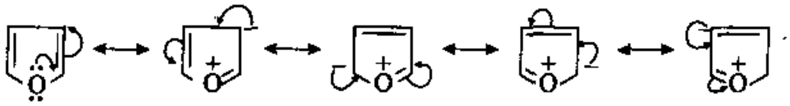


[II] Physical Properties

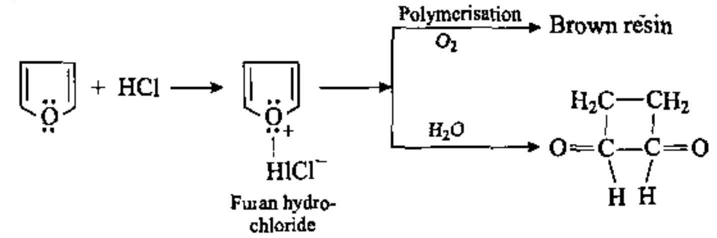
Furan is a colourless liquid, B.P. 32°C, with a chloroform like smell. It is insoluble in water but is soluble in most organic solvents.

[III] Chemical Properties

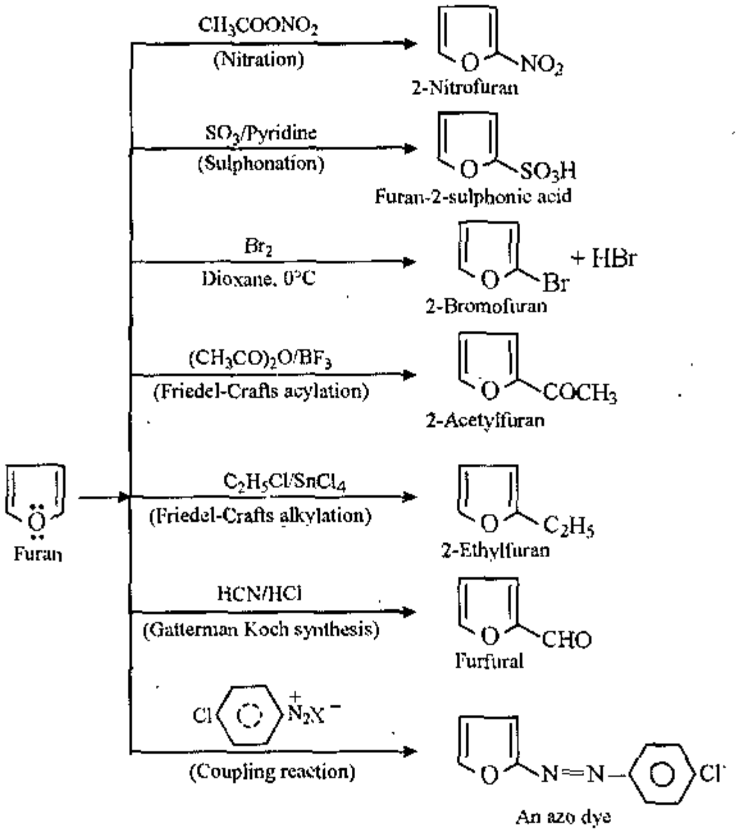
Furan is aromatic in nature and is the resonance hybrid of the following five resonating structures :



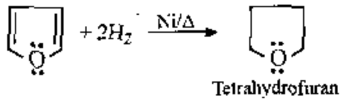
(1) Basic character : *Furan is a weak base. It forms unstable salts with mineral acids.* These salts may either polymerise and form a brown resin or undergo hydrolysis to form succinidialdehyde.



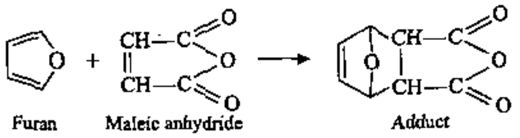
(2) Electrophillic substitution reactions : Furan undergoes electrophilic substitution *reactions chiefly at C—2 or C—5. Substitution at C—3 or C—4 occurs only* when both C—2 or C—5 positions are already occupied. The electrophilic substitution reactions of furan are not carried out in presence of strong acids, as it undergoes polymerisation. Some important reactions are given below.



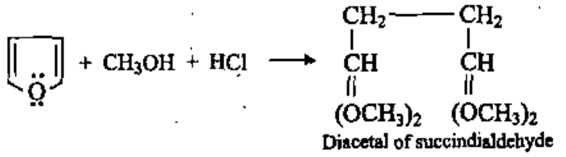
(3) Reduction : Furan is reduced by hydrogen in presence of nickel (catalyst) to form tetrahydrofuran (THF).



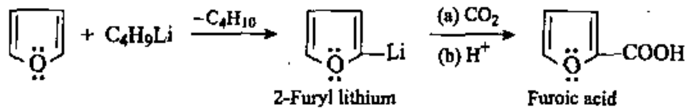
(4) Diels-Alder reaction : With maleic anhydride, *furan forms an addition product. The* addition occurs across C—2 and C—5 positions.



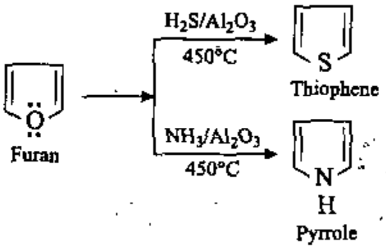
(5) Ring opening reaction : Furan when treated with methanol and hydrochloric acid undergoes ring opening with the formation of diacetal of succindialdehyde.



(6) Reaction with butyl lithium : Furan gives 2-furyl lithium which undergoes the usual reactions of organolithium compound.



(7) Conversion of furan into pyrrole and thiophene.

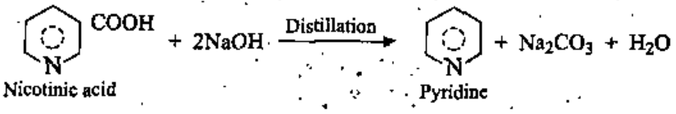


• 4.7. PYRIDINE

Pyridine is an important heterocyclic compound containing a six-membered ring. It may be considered as derived from benzene by the replacement of =CH— group by nitrogen atom =N—. It occurs in light oil fraction of coal tar and in bone oil.

[I] Preparation

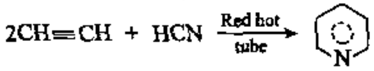
(i) Laboratory method : Pyridine is obtained by distilling nicotinic acid (pyridine β-carboxylic acid) with soda lime.



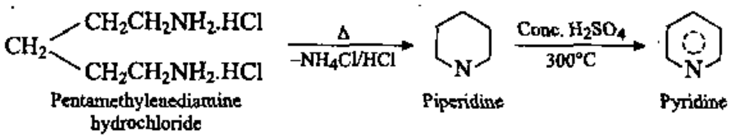
(ii) Manufacture : Commercially, pyridine is obtained from *light oil fraction* obtained by the fractional distillation of coal-tar. The fraction is treated with dilute H_2SO_4 which absorbs pyridine bases. The acid layer is separated and decomposed with Na_2CO_3. Thus, pyridine bases separate out as dark brown oil. Pyridine can be obtained from it by fractional distillation.

(iii) Synthesis :

(a) Pyridine is obtained by passing a mixture of acetylene and HCN through a red hot tube.

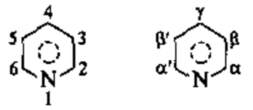


(b) Pyridine is also obtained by heating pentamethylene diamine hydrochloride followed by reaction with conc. H_2SO_4 at 300°C.



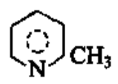
[II] Isomerism of Pyridine Derivatives

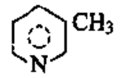
Pyridine ring consists of five carbon atoms and one nitrogen atom. The number of isomers depend on the relative positions of the substitutents as well as on their positions with respect to nitrogen. So, the substituted products may be as follows :

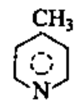


(i) Mono-substitution products : Three mono-substituted derivatives of pyridine (α, β, γ) are possible. These three positions in pyridine are similar to ortho, meta and para positions of benzene.

So, three methyl pyridines $C_5H_4N.CH_3$ (picoline) are possible.


α-Picoline


β-Picoline


γ-Picoline

Similarly, three pyridine mono-carboxylic acids (α, β, γ) $C_5H_4N.COOH$ are possible.


Picolinic acid


Nicotinic acid


Iso-nicotinic acid

(ii) Di-substitution products : If the two substitutent groups are similar then six di-substituted products (2 : 3, 2 : 4, 2 : 5, 2 : 6, 3 : 4, 3 : 5) *of pyridine are possible.*

[III] Physical Properties

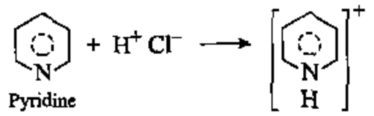
Pyridine is a colourless liquid with a characteristic smell *(B.P. = 116°C). It is soluble in water,* alcohol, ether etc. It is a weak tertiary base and can be distilled with decomposition. It is of hygroscopic nature.

[IV] Chemical Properties

Pyridine is basic in nature and resembles benzene in many of its properties.

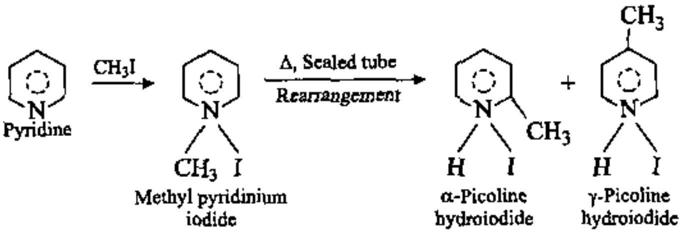
(1) Basic nature : The basic nature of pyridine is due to the availability of one pair of electrons on hetero-atom, *i.e.*, N. Due to this, it accepts a proton to form pyridinium ion. Thus, it is a tertiary base and gives salts with inorganic acids and forms quaternary salts when heated with alkyl halides.

$$\underset{\text{Pyridine}}{C_5H_5N} \xrightarrow{HCl} \underset{\text{Pyridine hydrochloride or pyridinium chloride}}{(C_5H_5N^+H)Cl^-}$$



Pyridinium ion

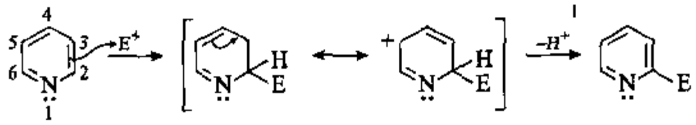
Pyridine reacts with methyl iodide and forms quaternary ammonium which when heated at 300°C in a sealed tube, rearranges to form 2-and 4-alkyl substituted pyridine *(Ladenberg's rearrangement).*



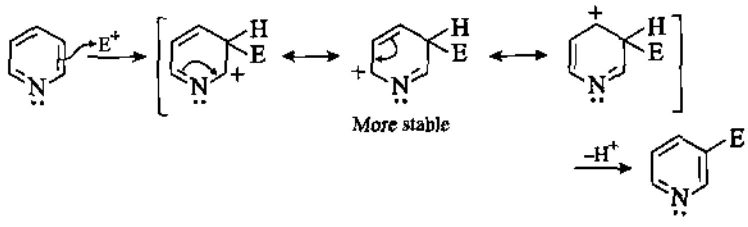
(2) Electrophilic substitution reactions : Pyridine undergoes electrophilic substitution *reactions at 3-positions only under vigorous conditions.*

Explanation : Attack of the electrophile at 2-position (or 4-position)–in pyridine leads to an *intermediate with only two important contributing structures.* Three resonance structures are possible for the intermediate produced by attack at 3-position, *i.e.*, the intermediate produced by the attack at 3-position *is more stable. This is the reason that* electrophilic attack occurs at 3-position. The symbol E^+ in the following equations denotes an electrophile.

(a) Attack at 2-position



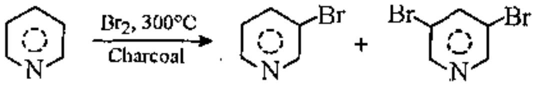
(b) Attack at 3-position



(i) Halogenation : Like benzene, pyridine is halogenated though less easily.

(a) At ordinary temperature, dihalide $[C_5H_5\overset{+}{N}Br]\,Br^-$ (1-bromo pyridinium bromide) is formed.

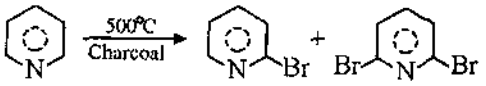
(b) At 300°C and in presence of charcoal (catalyst), 3-bromo- pyridine and 3, 5-dibromopyridine are obtained.



3-Bromo-pyridine

3-5-Dibromo-pyridine

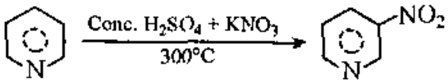
(c) At 500°C and in presence of catalyst, 2-bromopyridine and 2, 6-dibromopyridine are obtained.



2-Bromo-pyridine

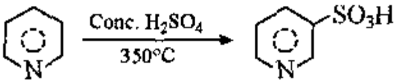
2-6-Dibromo-pyridine

(ii) Nitration : When heated with conc. H_2SO_4 and KNO_3 at 300°C, 3-nitropyridine is formed.



3-Nitropyridine

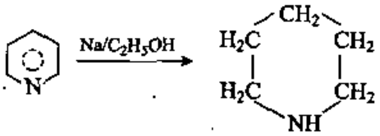
(iii) Sulphonation : The sulphonation of pyridine is difficult. If pyridine is heated with conc. H_2SO_4 at 350°C for a few hours, then pyridine 3-sulphonic acid is formed.



Pyridine 3-sulphonic acid

(iv) Reduction :

(a) Pyridine on reduction with sodium and ethanol in presence of nickel gives piperidine.



Piperidine

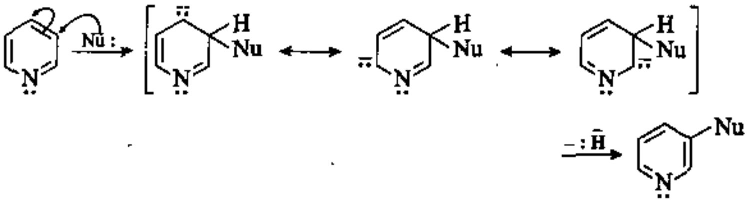
(b) On heating with HI at 300°C, the reduction takes place by ring fission to form *n*-pentane and ammonia.

$$\underset{\text{Pyridine}}{C_5H_5N} + 10HI \longrightarrow \underset{n\text{–Pentane}}{C_5H_{12}} + NH_3 + 5I_2$$

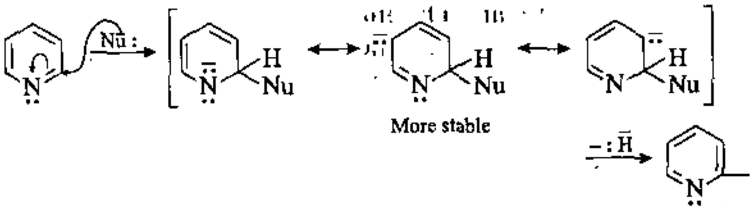
(3) Nucleophilic substitution reactions : In pyridine, nucleophilic substitution takes place with ease at 2- and 4-positions, *e.g.*, the hydrogen atoms of 2- and 4-positions are easily substituted by OH, CN and NH_2 groups.

Explanation : Attack of the nucleophile at 3-position in pyridine leads to an intermediate with three resonance contributing structures. Attack of the nucleophile at 2-position (or 4-position) also gives an intermediate with three resonance structures, 4-position is attacked only when 2-position is blocked. In the following equations $\bar{Nu}$: denotes a nucleophile.

(a) Attack at 3-position



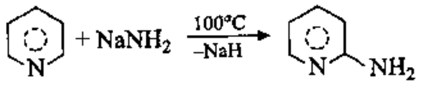
(b) Attack at 2-position



More stable

Favoured product

(i) Action of sodamide : On heating pyridine in toluene solution with sodamide ($NaNH_2$), 2-aminopyridine is formed.

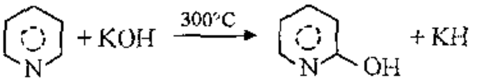


Pyridine 2-Amino pyridine

(ii) Action of organolithium compounds : 2-Phenylpyridine is obtained.

2-Butylpyridine 2-Phenylpyridine

(iii) Action of KOH : 2-Hydroxy pyridine is obtained.



2-Hydroxypyridine

[V] Uses

Pyridine is used :

(i) As a solvent.

(ii) In denaturing of alcohol.

(iii) In acetylation, benzoylation and molecular weight determinations of many acids and also as a catalyst in various reactions.

(iv) In the manufacture of derivatives like vitamin B_6 and sulphapyridine. *(Sulphapyridine drug has played an important role in curing pneumonia, gonorrhea and other infectious diseases).*

[VI] Structure

(1) Molecular formula : From elemental analysis and molecular weight determination the molecular formula of pyridine is found to be C_5H_5N.

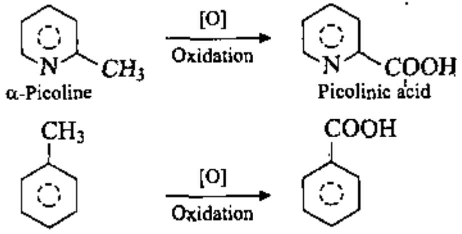
(2) Aromatic character : In most cases, pyridine resembles benzene, *e.g.*,

(a) It is a stable compound and is not oxidised by $KMnO_4$, HNO_3, K_2CrO_4, etc.

(b) Like benzene pyridine can be nitrated, sulphonated and halogenated.

(c) The amino derivatives of pyridine can be diazotized and coupled in the usual way.

(d) The hydroxy derivatives of pyridine show phenolic properties.



α-Picoline Picolinic acid

Toluene Benzoic acid

(e) Inspite of being unsaturated, pyridine gives substituted compounds with bromine and chlorine.

(f) On oxidation, alkyl pyridines give pyridine carboxylic acids.

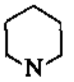
(3) Presence of a tertiary nitrogen atom : Pyridine reacts with alkyl halides to form quaternary salts.

$$\underset{\text{Pyridine}}{C_5H_5N} + CH_3I \longrightarrow \underset{\text{Methyl pyridinium iodide}}{[C_5H_5\overset{+}{N}.CH_3]\overset{-}{I}}$$

This clearly shows the presence of a tertiary nitrogen in pyridine.

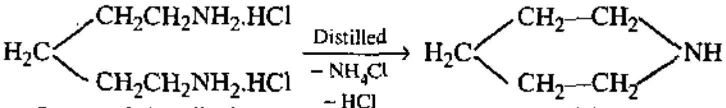
(4) Presence of 5 carbon atoms and a heterocyclic compound of a tertiary nitrogen atom and presence of three double bonds : On reduction with sodium and alcohol, pyridine takes up 6H atoms to form piperidine like benzene which forms cyclohexane. Addition of six hydrogen atoms suggests the presence of three double bonds in pyridine like benzene.

$$\underset{\text{Pyridine}}{C_5H_5N} + 6H \xrightarrow{\text{Reduction}} \underset{\text{Piperidine}}{C_5H_{11}N} \text{ or}$$



$$\underset{\text{Benzene}}{C_6H_6} + 6H \xrightarrow{\text{Reduction}} \underset{\text{Cyclohexane}}{C_6H_{12}}$$

Piperidine contains a six-membered ring of five carbon atoms and one nitrogen atom which can be shown from the following synthesis.

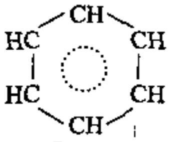


Penta-methylene diamine hydrochloride

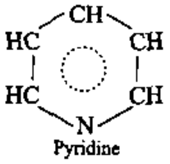
Piperidine

Piperidine is a closed chain compound and hence pyridine must also be a closed chain compound because piperidine is obtained by mere addition of hydrogen to pyridine.

(5) Korner's formula : Keeping all the above facts in view, Korner (1864) suggested the following ring structure for pyridine which is very similar to that of benzene.

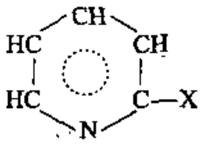


Benzene

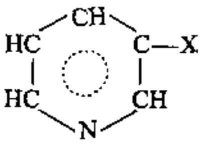


Pyridine

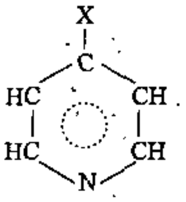
(6) Assuming the above structure of pyridine, it forms three possible mono-substituted compounds.



2-Substituted pyridine



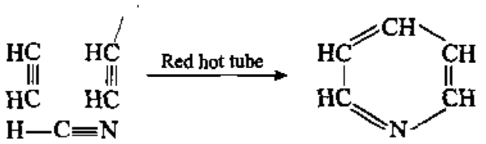
3-Substituted pyridine



4-Substituted pyridine

(7) Confirmation : The above structure has been confirmed by its synthesis.

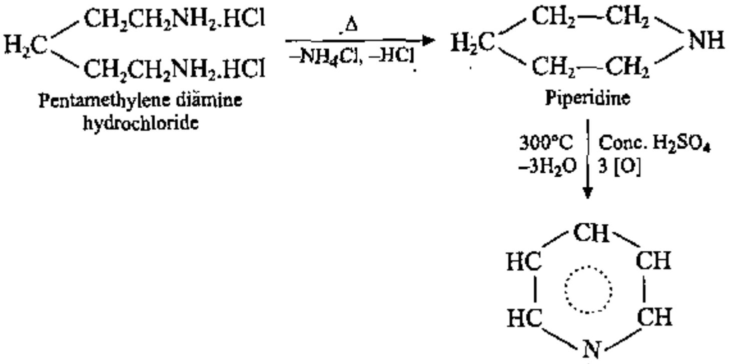
(a) When a mixture of acetylene and hydrogen cyanide is passed through a red hot tube, pyridine is formed.



Acetylene (2 moles) + one molecule of hydrogen cyanide

Pyridine

(b) Pentamethylene diamine hydrochloride on heating gives piperidine which on oxidation with conc. H_2SO_4 at 300°C gives pyridine.

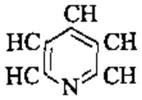


Pentamethylene diamine hydrochloride

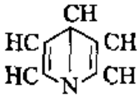
Piperidine

Pyridine

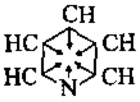
(8) Other formulae : Various other formulae were suggested for pyridine but they were rejected on the same ground as for benzene.



Korner (1869)



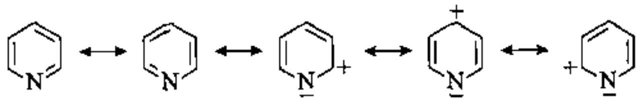
Reidel (1882)



Bamberger (1892)

However, the formula proposed by Korner best accounts for the properties of pyridine and the synthesis already cited goes to confirm it.

(9) Resonance formulae : Present view about the structure is that pyridine is a resonance hybrid of the following two Kekule's structures and three charged structures. The resonance energy of pyridine is 125.5 kJ mol^{-1}.

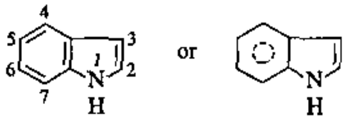


(I) (II) (III) (IV) (V)

The stability, aromatic character and formation of quaternary salts of pyridine find a satisfactory explanation in terms of resonance.

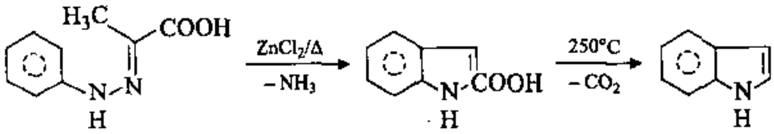
• 4.8. INDOLE

Indole is known as 2, 3 benzopyrrole (C_8H_7N). It is a five membered condensed heterocycle and is represented as :



[I] Preparation (Fisher-Indole Synthesis)

When phenylhydrazone of pyruvic acid, $CH_3—CO—COOH$ is heated with $ZnCl_2$ catalyst, it gives indole-2-carboxylic acid which decarboxylates to form indole.



Pyruvic acid phenylhydrazone

Indole-2-carboxylic acid

Indole

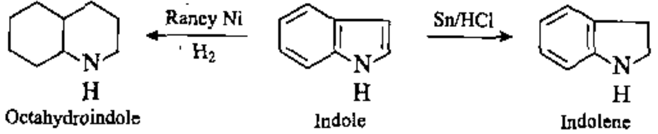
[II] Physical Properties

Indole forms colourless crystals, mpt. 52.5°C. It has a strong fecal odour. In dilute solutions, it has a flowery odour and is used in perfumery for preparing orange blends and jasmine. Indole is soluble in hot water, alcohol and ether.

[III] Chemical Properties

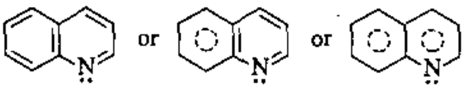
Chemically, *indole resembles pyrrole*. It is basic and gives electrophilic substitution reactions, such as nitration, sulphonation and halogenation at 3-position. It is due to greater stabilisation of carbonium ion intermediate as compared to that in 2-substitution. If both 2- and 3-positions are occupied, substitution occurs at *6-position in the benzene ring.*

On reduction, indole forms indoline (2, 3 dihydroindole) and octahydroindole.



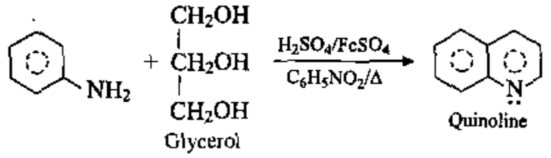
• 4.9. QUINOLINE

Quinoline is a bicyclic heterocyclic compound having a benzene ring fused with a pyridine ring in 2, 3 positions or it is a six membered condensed heterocycle. It may also be considered as naphthalene in which one CH in position-1 has been replaced by N. Quinoline is also known as 1-azanaphthalene.



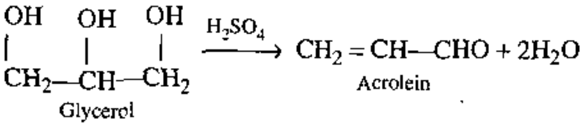
[I] Preparation (Skraup's Synthesis)

To obtain quinoline a mixture of aniline, glycerol and sulphuric acid is heated in presence of a mild oxidising agent such as nitrobenzene. The reaction is exothermic and so it tends to be violent and $FeSO_4$ is also added as a moderator.



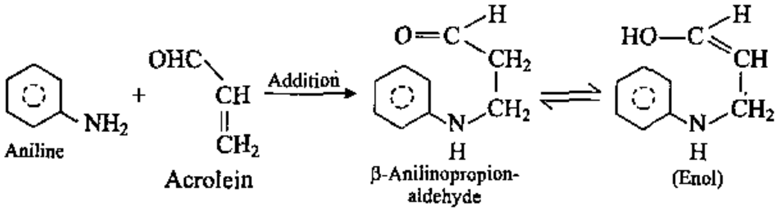
Mechanism : The Skraup's synthesis is supposed to proceed by the following steps :

(i) Glycerol dehydrates with H_2SO_4 to form acrolein.

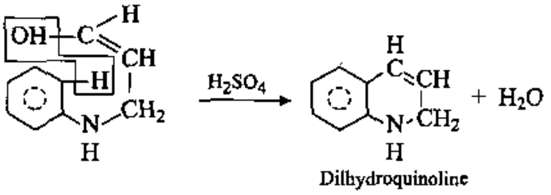


$$\underset{\text{Glycerol}}{\overset{\text{OH}}{\underset{|}{}}\!\text{CH}_2\!-\!\overset{\text{OH}}{\text{CH}}\!-\!\overset{\text{OH}}{\text{CH}_2}} \xrightarrow{H_2SO_4} \underset{\text{Acrolein}}{CH_2=CH-CHO} + 2H_2O$$

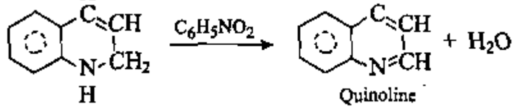
(ii) Acrolein undergoes 1, 4-addition with aniline.



(iii) Resulting β-anilinopropionaldehyde cyclizes to form dihydroquinoline.



(iv) Dihydroquinoline is oxidised to quinoline, while nitrobenzene is reduced to aniline which is re-used.



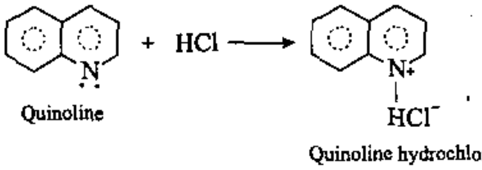
[II] Physical Properties

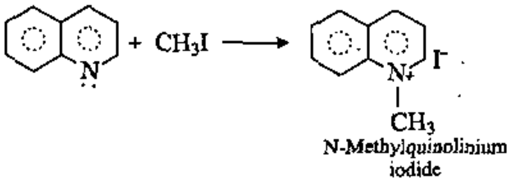
Quinoline is a colourless liquid, B.Pt. = 238°C. It has a disagreeable pyridine like odour. It is soluble in water and completely miscible with alcohol, acetone and ether.

[III] Chemical Properties

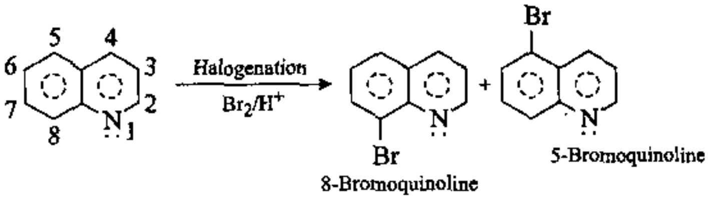
Chemically, quinoline gives all the reactions of pyridine and electrophilic substitution reactions of the benzene ring.

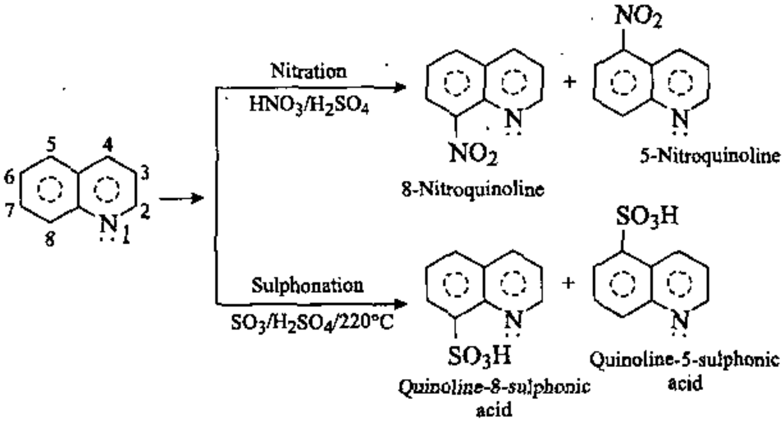
(1) Formation of salts : Quinoline is slightly weaker base ($K_b = 6.3 \times 10^{-10}$) than pyridine. Like other tertiary bases, it forms salts with acids and reacts with alkyl halides to form quaternary salts.



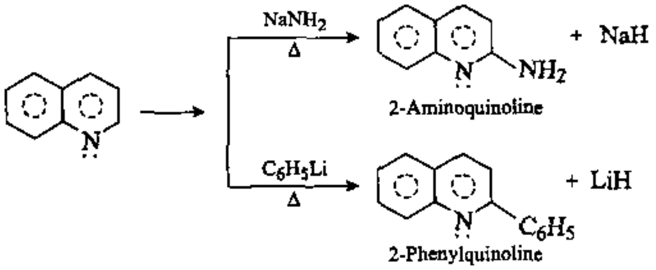


(2) Electrophilic substitution reactions : Quinoline gives electrophilic substitution reactions in the benzene ring and not in the more resistant pyridine ring. The electrophile preferably attacks position 8 and 5.

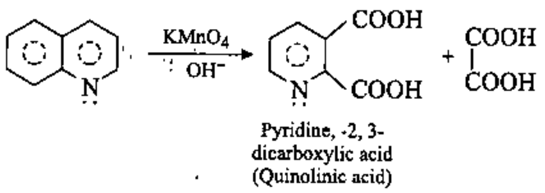




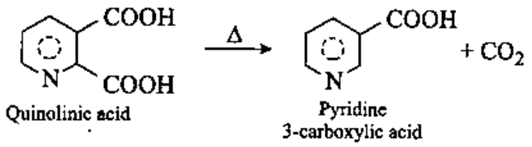
(3) Nucleophilic substitution reactions : These reactions occur at positions 2- and 4- in quinoline which is electron deficient due to electron withdrawl by nitrogen atom (compare with pyridine).



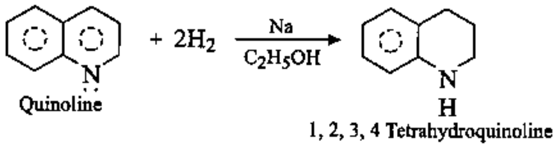
(4) Oxidation : On vigorous oxidation, with alkaline potassium permanganate, quinoline gives pyridine 2, 3-dicarboxylic acid.



On heating, quinolinic acid decarboxylates to give pyridine-3- carboxylic acid (nicotinic acid).



(5) Reduction : Quinoline is easily reduced to form 1, 2, 3, 4- tetrahydroquinoline. The benzene ring being more resistant is not reduced.



The reduction can also be carried out with Sn/HCl or Zn/CH_3COOH.

[IV] Uses

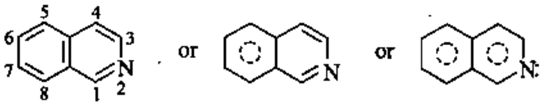
Quinoline is used :

(i) As a high boiling basic solvent in organic reactions.

(ii) In the manufacture of dyes, pharmaceuticals and insecticides.

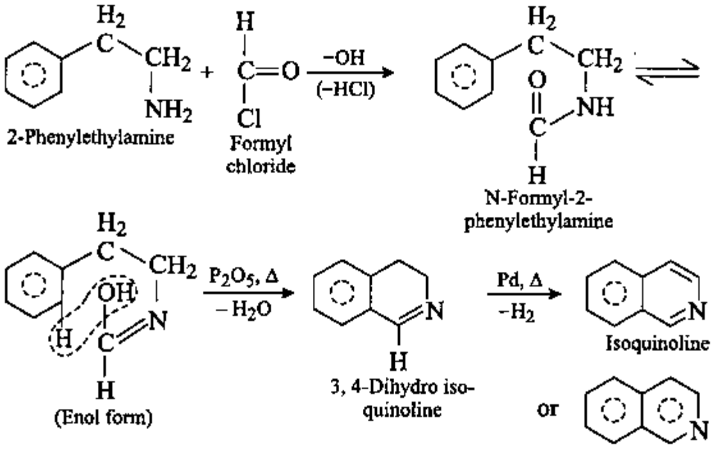
• 4.10. ISOQUINOLINE

Isoquinoline is also a six membered condensed heterocyclic compound and is also known as 2-azanaphthalene. It is represented as :

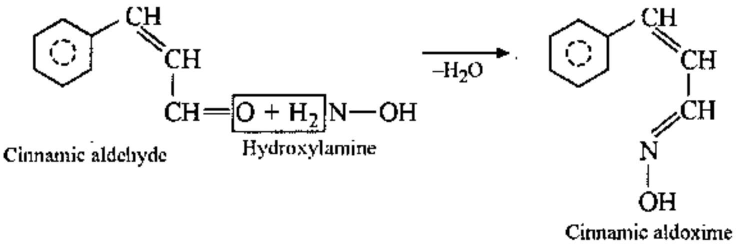


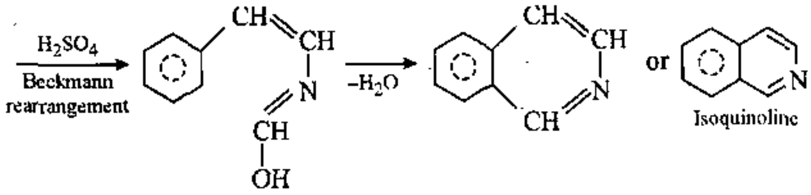
[I] Preparation

(i) From Bischler-Bapieralski synthesis.



(ii) From cinnamic aldehyde.





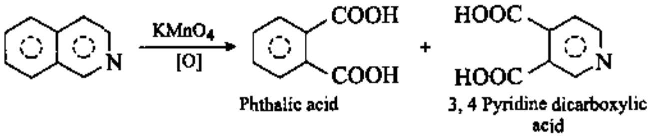
[II] Physical Properties

Isoquinoline is a colourless solid or liquid M.Pt. = 23°C, B.Pt. = 243°C. It s insoluble in water and soluble in most of the organic solvents.

[III] Chemical Properties

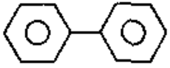
Chemically, isoquinoline closely resembles quinoline. Thus, it is also a monoacid tertiary base and is reduced to 1, 2, 3, 4-tetrahydro- isoquinoline. It undergoes electrophilic substitution reactions, *e.g.*, sulphonation and nitration at 5–or 8–position and bromination at 4-position. The nucleophilic substitution reactions occur most readily at position-1.

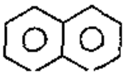
On oxidation with $KMnO_4$, isoquinoline forms *phthalic acid* and *3, 4 pyridine dicarboxylic* acid.



• SUMMARY

- Polynuclear hydrocarbons contain more than one aromatic rings.
- Polynuclear hydrocarbons are of two types, *viz.;*

  isolated polynuclear hydrocarbons, *e.g.*,  (Diphenyl)

  and fused polynuclear hydrocarbons, *e.g.*,  (Naphthalene)
- In naphthalene, two benzene rings are fused in ortho positions.
- Heterocyclic compounds are cyclic compounds which have hetero atom(s) at one or more corners of the ring in addition to carbon atoms, *e.g.*, furan, pyrrole, thiophene.
- *Pyridine has a tertiary nitrogen present and contains three* double bonds.
- **Skraup's synthesis :** A mixture of aniline, glycerol and sulphuric acid is heated in presence of mild oxidising agent ($C_6H_5NO_2$) and $FeSO_4$ is added as a moderator to obtain quinoline.

• STUDENT ACTIVITY

1. How is naphthalene prepared from benzene ?

2. What are heterocyclic compounds ?

3. Describe the electrophilic substitution reactions of thiophene.

4. Mention Fischer-indole synthesis.

5. Mention Skraup's synthesis.

• TEST YOURSELF

1. What are polynuclear hydrocarbons ?
2. Describe the methods for the preparation of naphthalene.
3. Discuss the important properties and uses of naphthalene.
4. Starting from naphthalene, how will you obtain the following compounds ?
    - (i) α-Naphthol
    - (ii) β-Naphthol
    - (iii) α-Naphthylamine
    - (iv) β-Naphthylamine
    - (v) α-Nitronaphthalene
    - (vi) β-Nitronaphthalene
    - (vii) α-Chloronaphthalene
    - (viii) β-Chloronaphthalene
    - (ix) Phthalic acid
    - (x) Phthalimide
    - (xi) Anthranilic acid
    - (xii) Tetralin
    - (xiii) Decalin
    - (xiv) Salicyclic acid
    - (xv) Phthalic anhydride
    - (xvi) Aspirin
    - (xvii) Phenolphthalein
    - (xviii) Oil of winter green
5. Describe the methods of preparation, properties and uses of anthracene.
6. How is alizarin obtained from anthracene ?
7. What are heterocyclic compounds and give their characteristics ? Classify them.
8. Name three aliphatic substances which may be regarded as heterocyclic in nature.
9. How pyrrole differs and resembles from aromatic compounds ?
10. How is pyrrole prepared ?
11. Describe the preparation and properties of the following compounds :
    - (i) Thiophene
    - (ii) Furan
    - (iii) Pyridine

12. Show that pyridine is a heterocyclic compound having one nitrogen atom.
13. Describe Fischer-indole synthesis.
14. Describe the reactions of indole and explain the mchanism of electrophilic substitution reactions of indole.
15. What is quinoline ? Mention Skraup's synthesis including its mechanism.
16. Describe the properties and uses of quinoline.
17. What is isoquinoline ? Describe Bischler-Bapierlski synthesis of isoquinoline.
18. Describe the important chemical properties of isoquinoline.
19. Naphthalene may be purified by :
    (a) Crystallization (b) Distillation (c) Sublimation (d) Steam distillation
20. The number of isomeric mono-substituted derivatives formed by anthracene are :
    (a) 2 (b) 3 (c) 4 (d) 5
21. Which one of the following does not contain pyrrole ring ?
    (a) Chlorophyll (b) Haemoglobin (c) Camphor (d) Nicotine
22. Which one is most reactive ?
    (a) Pyrrole (b) Furan (c) Thiophene (d) Benzene
23. Which one of the following will show Diel's Alder reaction ?
    (a) Pyrrole (b) Furan (c) Thiophene (d) Pyridine
24. Benzene and thiophene can be separated by :
    (a) Fractional distillation (b) Conc. HCl
    (c) Conc. H_2SO_4 (d) Conc. HNO_3
25. Thiophene on treatment with isatin and H_2SO_4 gives the following colour :
    (a) Blue (b) Black (c) Red (d) Green

26 Fill in the blanks :

(i) *In naphthalene each carbon atom is .... hybridized.*
(ii) Anthracene is obtained from .... fraction of coal tar.
(iii) Pyridine reacts with sodamide in toluene solution to obtain ....
(iv) Pyrrole resembles with .... and .... in chemical properties.
(v) Pyridine is .... basic than pyrrole.
(vi) Pyridine is obtained from .... fraction of coal tar.
(vii) Pyridine on reduction with HI at 300°C gives .... and ....

ANSWERS

19. (c) **20.** (b) **21.** (c) **22.** (a) **23.** (b) **24.** (c) **25.** (a)
26. **(i)** sp^2 **(ii)** green oil **(iii)** 2-aminopyridine **(iv)** phenol, aromatic amines
(v) more **(vi)** light oil **(vii)** n-pentane, ammonia.

❑❑❑

UNIT

5

REACTIVE METHYLENE COMPOUNDS

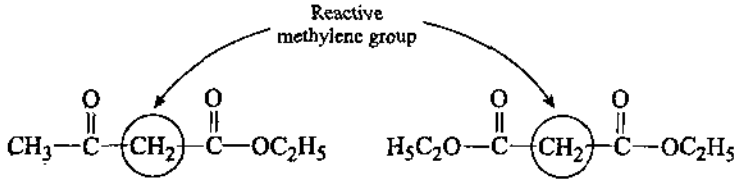
LEARNING OBJECTIVES

- Reactive Methylene Group
- Acidity of α-Hydrogens
- Diethyl Malonate or Malonio Ester
- Acetoacetic Ester or Ethyl Acetoacetate
- Claisen Condensation
- Keto-Enol Tautomerism
    - Summary
    - Student Activity
    - Test Yourself

• 5.1. REACTIVE METHYLENE GROUP

[I] Reactive Methylene Group

A methylene group (—CH_2—) directly bonded to two electron withdrawing groups such as —$COCH_3$, —$COOC_2H_5$, —CN is known as a ***reactive methylene group***. This is so because the —CH_2— group in the above mentioned groups is acidic and reactive. The class of compounds containing a reactive methylene group is known as ***active methylene compounds***. Ethyl acetoacetate (acetoacetic ester) and diethyl malonate (malonic ester) belong to this class.



Ethyl acetoacetate
(Acetoacetic ester)

Diethyl malonate
(Malonic ester)

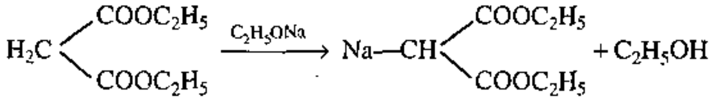
[II] Compounds Not Containing Reactive Methylene Group

Compounds like propane, acetone, ethyl acetate etc. contain a methylene group which is either placed between two electropositive groups or one electropositive and one electronegative group. Therefore, they do not contain an active methylene group.

$$\underset{\text{Propane}}{CH_3—CH_2—CH_3}, \quad \underset{\text{Acetone}}{H—CH_2—COCH_3}, \quad \underset{\text{Ethyl acetate}}{H—CH_2—COOC_2H_5},$$

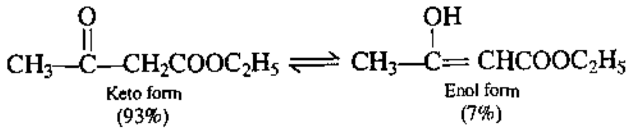
[III] Main Characteristics of Compounds Containing Reactive Methylene Group

(i) Form sodio-derivatives with Na or C_2H_5ONa.



$$H_2C\begin{matrix}\diagup COOC_2H_5 \\ \diagdown COOC_2H_5\end{matrix} \xrightarrow{C_2H_5ONa} Na—CH\begin{matrix}\diagup COOC_2H_5 \\ \diagdown COOC_2H_5\end{matrix} + C_2H_5OH$$

(ii) Exhibit tautomerism and hence can exist in keto and enol forms, *e.g.*, ethyl acetoacetate exists as follows :

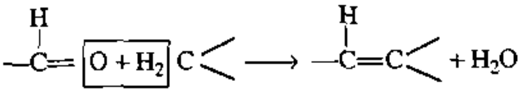


$$CH_3-\overset{\overset{O}{\|}}{C}-CH_2COOC_2H_5 \rightleftharpoons CH_3-\overset{\overset{OH}{|}}{C}=CHCOOC_2H_5$$

Keto form (93%)

Enol form (7%)

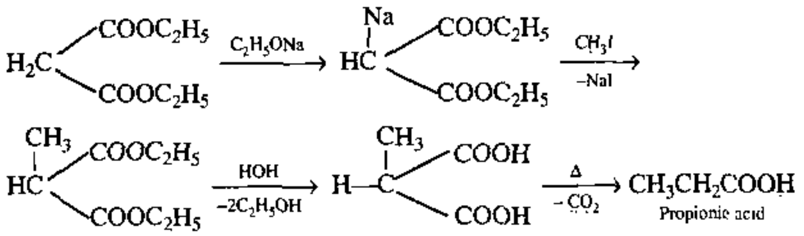
(iii) React with oxygen of aldehydes forming unsaturated compounds.



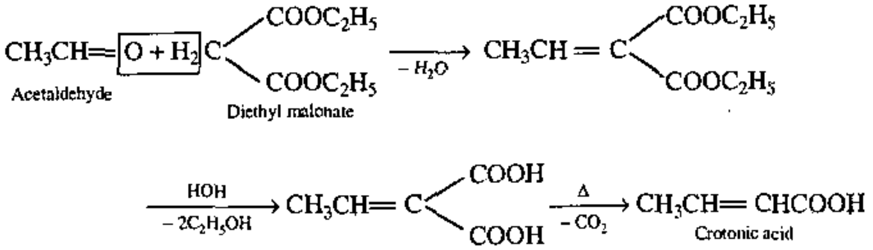
$$-\overset{\overset{H}{|}}{C}=\boxed{O+H_2}C\Big< \longrightarrow -\overset{\overset{H}{|}}{C}=C\Big< +H_2O$$

[IV] Synthetic Importance

(1) The hydrogen atoms of the —CH_2 group can be easily replaced with sodium one by one. The sodio-derivatives so obtained can readily react with compounds containing reactive halogen like CH_3I, CH_3COCl etc. to form a variety of important compounds.

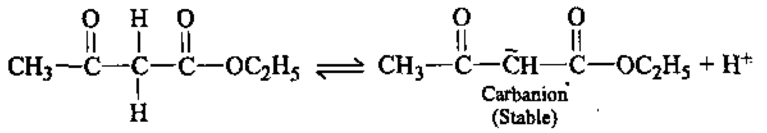


(2) The hydrogen atoms of —CH_2— group can react with oxygen of aldehydes to form unsaturated compounds.



• 5.2. ACIDITY OF α-HYDROGENS

Ethyl acetoacetate contains a methylene group (—CH_2—) joined to two carbonyl groups. The C—H bond in CH_2 group is readily ionisable because the proton removal forms a very stable carbanion.

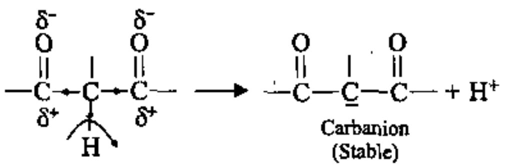


$$CH_3-\overset{\overset{O}{\|}}{C}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\overset{\overset{O}{\|}}{C}-OC_2H_5 \rightleftharpoons CH_3-\overset{\overset{O}{\|}}{C}-\bar{C}H-\overset{\overset{O}{\|}}{C}-OC_2H_5+H^+$$

Carbanion (Stable)

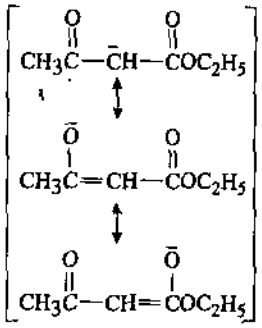
The acidity of the C—H bond of methylene group is due to the following two factors :

(i) Inductive effect : The inductive effect caused by the electron attracting power of the electronegative oxygens of the two carbonyl groups weaken the C—H bonds. So, the H atom can dissociate to give a stable anion.

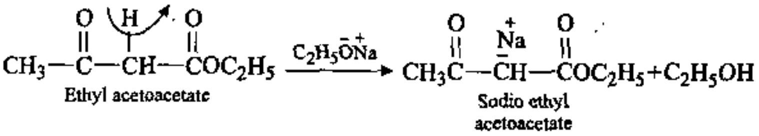


(ii) Resonance stabilisation of carbanion : The acidity of the C—H bond is appreciably increased because the negative charge in the carbanion is delocalised into the two carbonyl groups by resonance. The highly resonance stabilised carbanion may be shown as :

Ethyl acetoacetate is quite acidic and when treated with a strong base such as sodium ethoxide (C_2H_5ONa), forms its sodium salt.

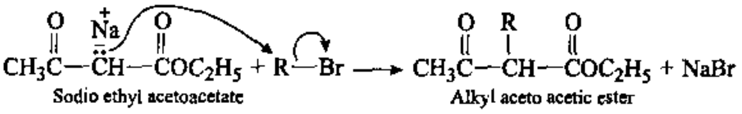


$$\left[\mathrm{CH_3\overset{O}{\overset{\|}{C}}-\overset{-}{C}H-\overset{O}{\overset{\|}{C}}OC_2H_5} \leftrightarrow \mathrm{CH_3\overset{\bar{O}}{\overset{|}{C}}=CH-\overset{O}{\overset{\|}{C}}OC_2H_5} \leftrightarrow \mathrm{CH_3\overset{O}{\overset{\|}{C}}-CH=\overset{\bar{O}}{\overset{|}{C}}OC_2H_5}\right]$$



$$\mathrm{CH_3-\overset{O}{\overset{\|}{C}}-\overset{H}{\overset{|}{C}}H-\overset{O}{\overset{\|}{C}}OC_2H_5} \xrightarrow{\mathrm{C_2H_5\bar{O}\overset{+}{N}a}} \mathrm{CH_3\overset{O}{\overset{\|}{C}}-\overset{\overset{+}{Na}}{\overset{-}{C}H}-\overset{O}{\overset{\|}{C}}OC_2H_5+C_2H_5OH}$$

Alkylation : Ethyl acetoacetate anion is nucleophilic and reacts with alkyl halides to give alkyl acetoacetic ester.



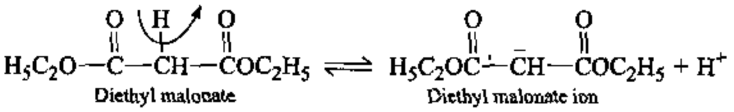
$$\mathrm{CH_3\overset{O}{\overset{\|}{C}}-\overset{\overset{+}{Na}}{\ddot{C}H}-\overset{O}{\overset{\|}{C}}OC_2H_5 + R-Br \longrightarrow CH_3\overset{O}{\overset{\|}{C}}-\overset{R}{\overset{|}{C}H}-\overset{O}{\overset{\|}{C}}OC_2H_5 + NaBr}$$

[II] Acidity of α-Hydrogens in Diethyl Malonate

Like ethyl acetoacetate, diethyl malonate also contains a methylene group joined to two carbonyl groups. The H atoms of the CH_2 group are acidic. They are also due to the same two factors, *viz.*,

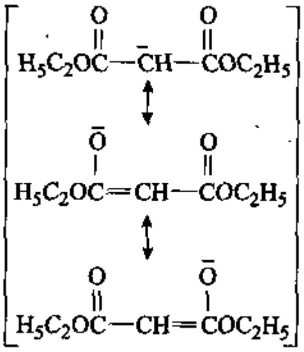
(i) ***Inductive effect,*** *i.e.*, the electron attracting power of the electronegative oxygen of the carbonyl group and

(ii) Resonance stabilisation of the resultant anion (diethyl malonate anion).



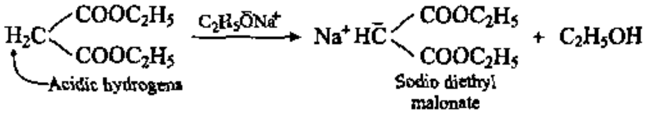
$$\mathrm{H_5C_2O-\overset{O}{\overset{\|}{C}}-\overset{H}{\overset{|}{C}}H-\overset{O}{\overset{\|}{C}}OC_2H_5} \rightleftharpoons \mathrm{H_5C_2O\overset{O}{\overset{\|}{C}}-\overset{-}{C}H-\overset{O}{\overset{\|}{C}}OC_2H_5 + H^+}$$

So, the diethyl malonate anion is highly resonance stabilised so that its negative charge is delocalised into two carbonyl groups.



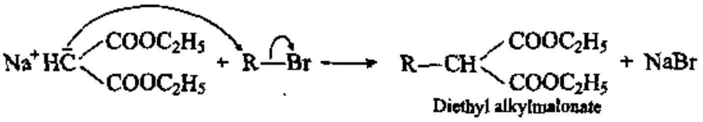
$$\left[\mathrm{H_5C_2O\overset{O}{\overset{\|}{C}}-\overset{-}{C}H-\overset{O}{\overset{\|}{C}}OC_2H_5} \leftrightarrow \mathrm{H_5C_2O\overset{\bar{O}}{\overset{|}{C}}=CH-\overset{O}{\overset{\|}{C}}OC_2H_5} \leftrightarrow \mathrm{H_5C_2O\overset{O}{\overset{\|}{C}}-CH=\overset{\bar{O}}{\overset{|}{C}}OC_2H_5}\right]$$

Therefore, CH_2 group being quite acidic, diethyl malonate reacts with strong base like sodium ethoxide (C_2H_5ONa) to form the sodium salt.



$$\mathrm{H_2C\begin{cases}COOC_2H_5\\COOC_2H_5\end{cases}} \xrightarrow{\mathrm{C_2H_5\bar{O}Na^+}} \mathrm{Na^+H\bar{C}\begin{cases}COOC_2H_5\\COOC_2H_5\end{cases} + C_2H_5OH}$$

Alkylation : Diethyl malonate anion is nucleophilic and reacts with alkyl halides to form diethyl alkylmalonate.



$$\mathrm{Na^+H\bar{C}\begin{cases}COOC_2H_5\\COOC_2H_5\end{cases} + R-Br \longrightarrow R-CH\begin{cases}COOC_2H_5\\COOC_2H_5\end{cases} + NaBr}$$

• 5.3. DIETHYL MALONATE OR MALONIC ESTER

[I] Preparation

Diethyl Malonate is obtained by the Interaction of acetic acid and chlorine as follows :

(i) *Monochloroacetic acid is obtained* by the treatment of acetic acid with chlorine.

(ii) Monochloro acetic acid is neutralised in aqueous solution with K_2CO_3 to obtain potassium chloroacetate.

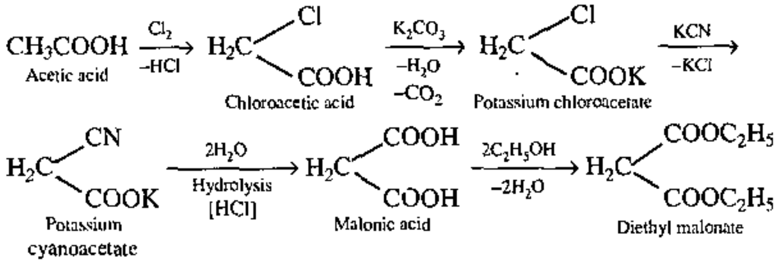
(iii) Potassium chloroacetate is then treated with KCN and the solution evaporated to dryness to obtain potassium cyanoacetate.

(iv) Potassium cyanoacetate is heated with absolute alcohol in presence of dry HCl gas when hydrolysis and esterification take place simultaneously with the formation of *diethyl malonate.*

(vi) The ethereal layer is washed, dried over anhydrous $CaCl_2$ and distilled to recover ether.

(v) The product is cooled and poured in ice cold water and the malonic ester so obtained is extracted with ether.

(vii) The oily residue is fractionally distilled and the fraction obtained between 195°—200°C is pure diethyl malonate.

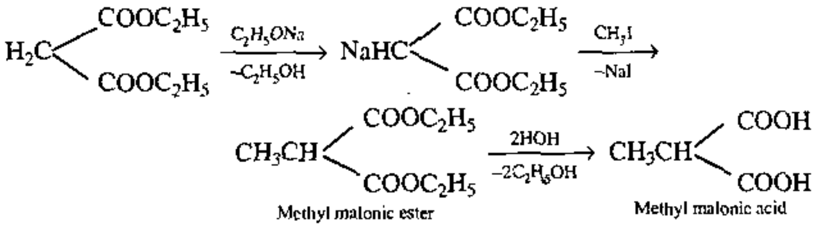


[II] Physical Properties

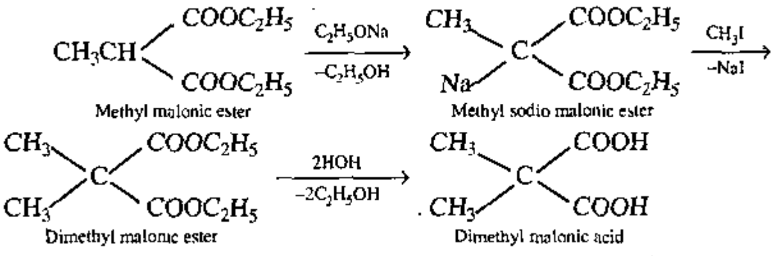
Diethyl malonate is a colourless, pleasant smelling liquid, boiling point = 199°C. It is sparingly *soluble in water.*

[III] Synthetic Importance

(1) Synthesis of Substituted Malonic Acids

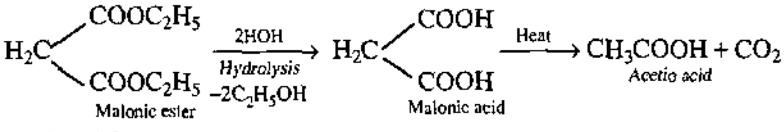


(a) Dialkyl malonic acid.

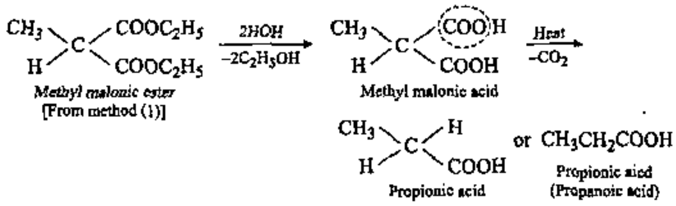


(2) Synthesis of Monobasic Acids

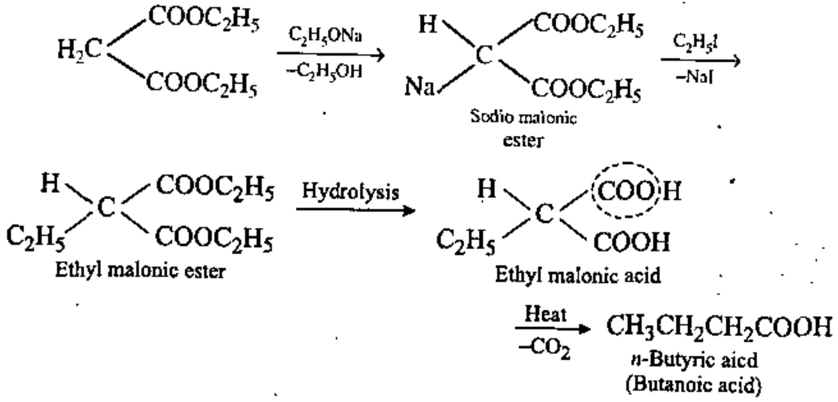
(a) Acetic acid.



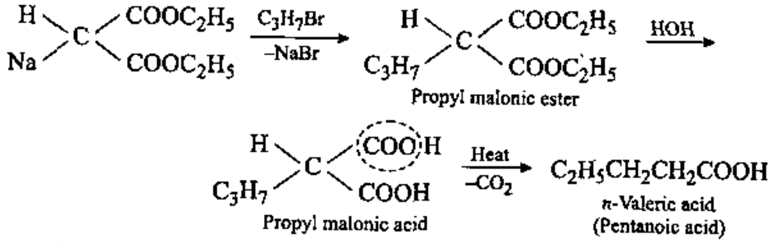
(b) Propionic acid.



(c) ***n*-Butyric acid.**



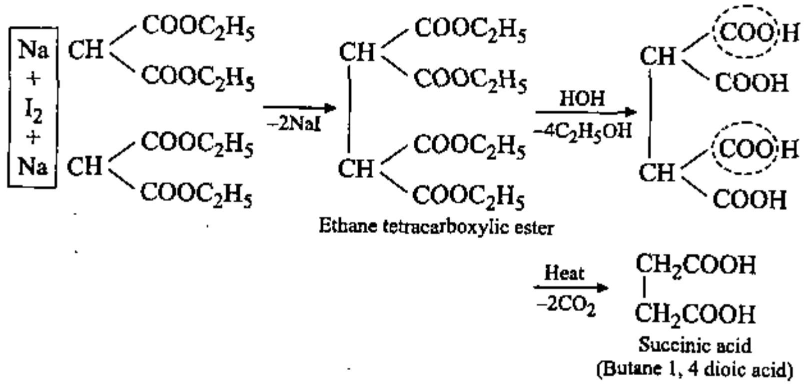
(d) ***n*-Valeric acid. or pentanoic acid**



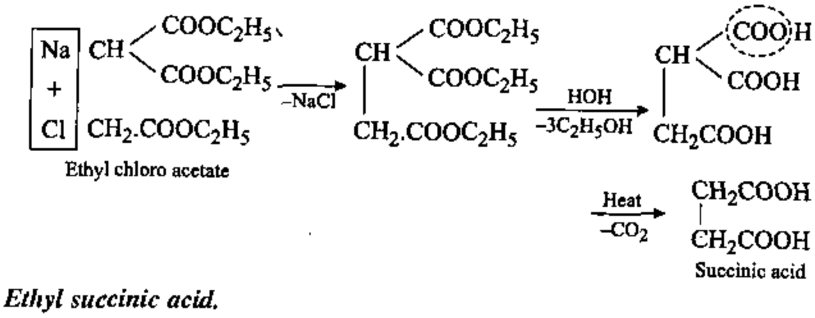
(3) Synthesis of Dibasic Acids

(a) ***Succinic acid.***

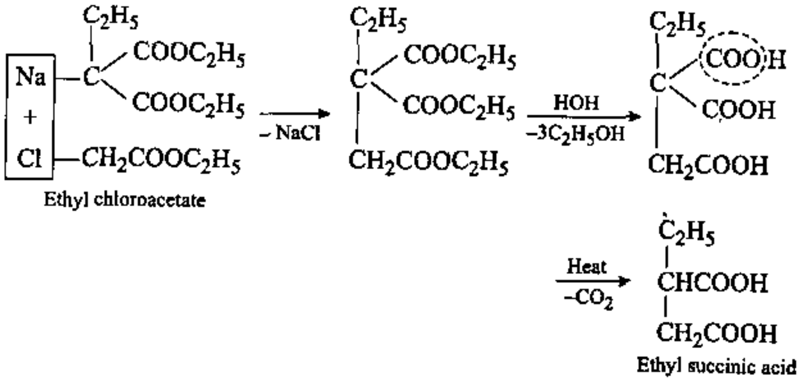
(i)



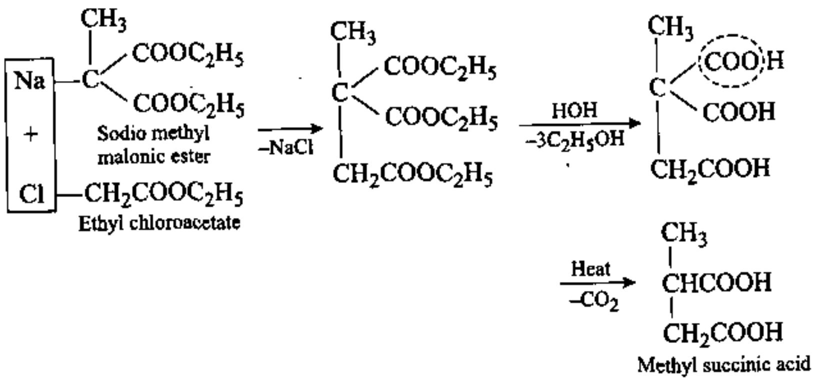
(ii) Succinic acid can also be prepared as follows :



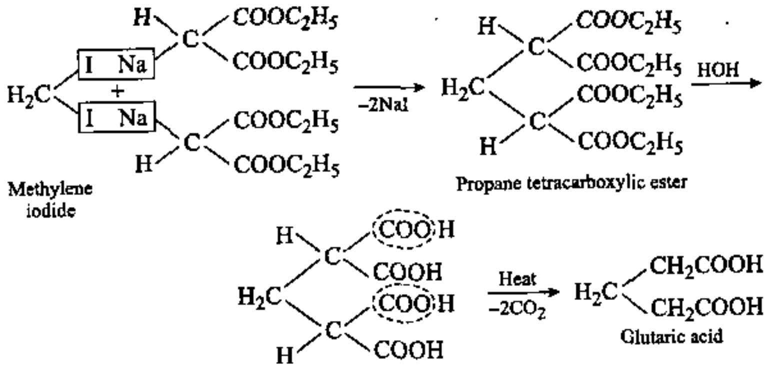
(b) ***Ethyl succinic acid.***



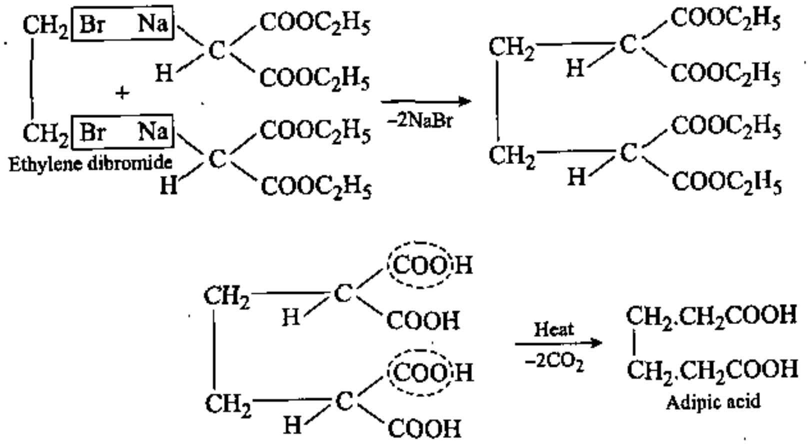
(c) Methyl succinic acid.



(d) Glutaric acid.

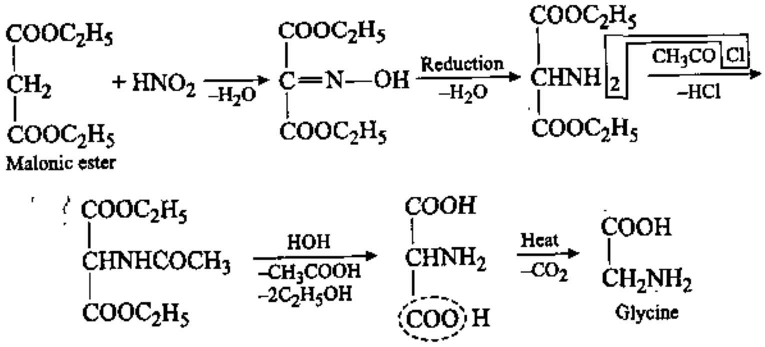


(e) Adipic acid.



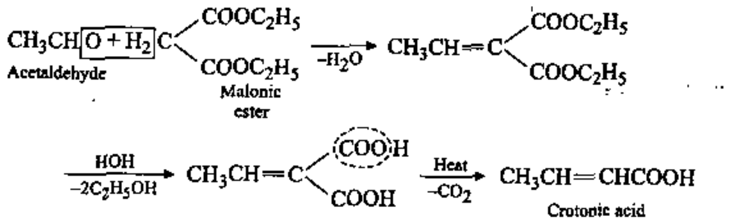
(4) Synthesis of Amino Acids

(a) Glycine :

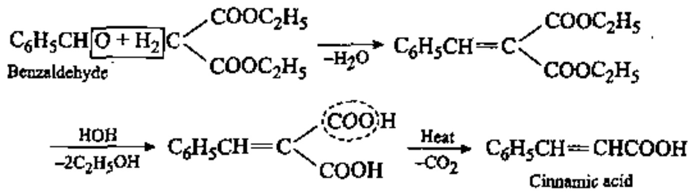


(5) Synthesis of Unsaturated Acids

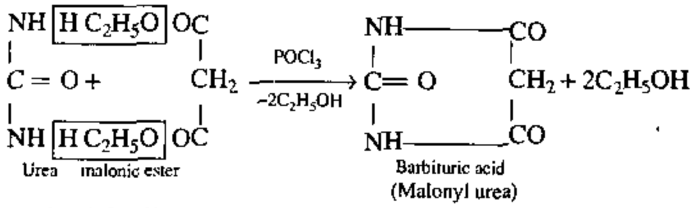
(a) Crotonic acid.



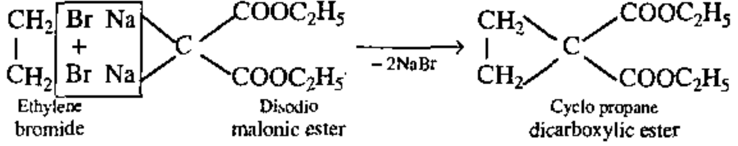
(b) Cinnamic acid.



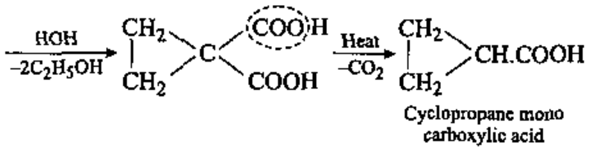
(6) Synthesis of Barbituric acid : Malonic ester condenses with urea to form barbituric acid.



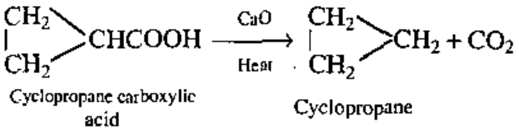
(7) Synthesis of Cyclic Acids



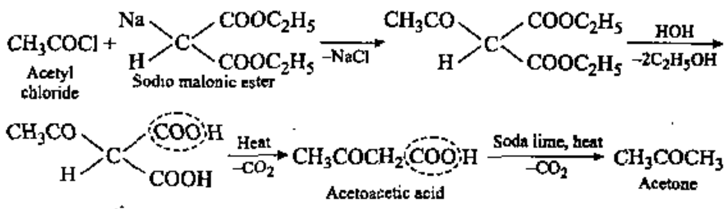
(8) Synthesis of Cyclic Compounds



(a) Cyclopropane : From cyclopropane mono carboxylic acid obtained as above ? Cyclopropane is obtained by heating the former with Soda line.



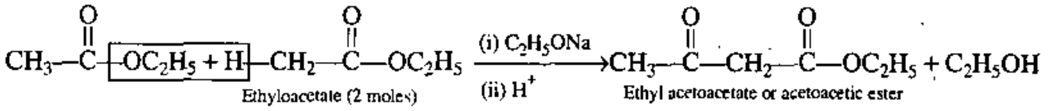
(9) Synthesis of Ketonic Acids and Ketones



• 5.4. ACETOACETIC ESTER OR ETHYL ACETOACETATE

[I] Preparation

When ethylacetate is heated in presence of sodium ethoxide (C_2H_5ONa) and then acidified, ethyl acetoacetate is obtained **(Claisen condensation).**



$$CH_3-\overset{O}{\overset{\|}{C}}-\boxed{OC_2H_5+H}-CH_2-\overset{O}{\overset{\|}{C}}-OC_2H_5 \xrightarrow[\text{(ii) }H^+]{\text{(i) }C_2H_5ONa} CH_3-\overset{O}{\overset{\|}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OC_2H_5+C_2H_5OH$$

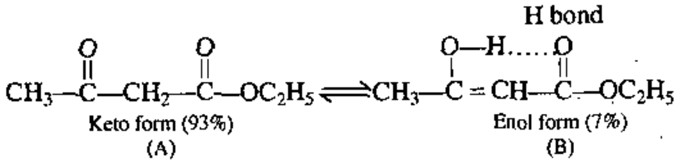
Ethyloacetate (2 moles)   Ethyl acetoacetate or acetoacetic ester

[II] Physical Properties

Ethyl acetoacetate is a colourless pleasant smelling liquid, B.Pt. = 184.4°C. It is sparingly soluble in water but freely soluble in organic solvents.

[III] Chemical Properties

In fact, ethyl acetoacetate is a tautomeric mixture of keto and enol forms as follows :

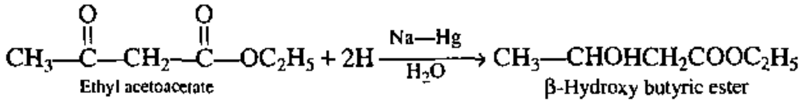


$$\underset{\text{Keto form (93\%) (A)}}{CH_3-\overset{O}{\overset{\|}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OC_2H_5} \rightleftharpoons \underset{\text{Enol form (7\%) (B)}}{CH_3-\overset{O-H.....O}{C=CH-\overset{\|}{C}}-OC_2H_5}$$

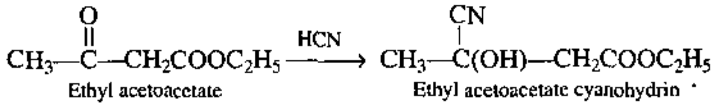
H bond

Hence, ethyl acetoacetate gives the reactions of both ketonic and enolic forms.

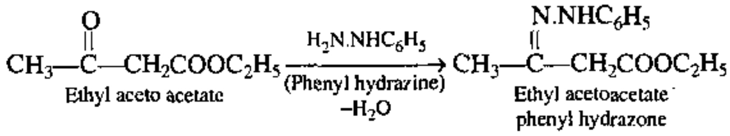
(1) Properties due to ketonic form.

(a) 

$$\underset{\text{Ethyl acetoacetate}}{CH_3-\overset{O}{\overset{\|}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OC_2H_5} + 2H \xrightarrow[H_2O]{Na-Hg} \underset{\beta\text{-Hydroxy butyric ester}}{CH_3-CHOHCH_2COOC_2H_5}$$

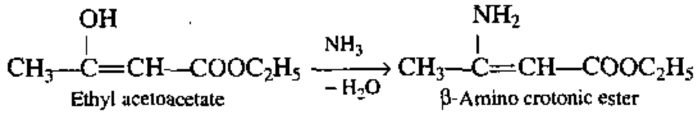
(b) 

$$\underset{\text{Ethyl acetoacetate}}{CH_3-\overset{O}{\overset{\|}{C}}-CH_2COOC_2H_5} \xrightarrow{HCN} \underset{\text{Ethyl acetoacetate cyanohydrin}}{CH_3-\overset{CN}{\overset{|}{C}}(OH)-CH_2COOC_2H_5}$$

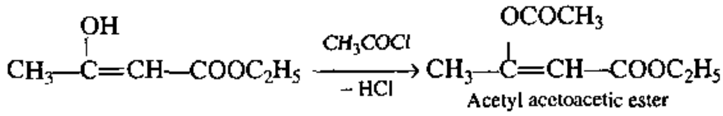
(c) 

$$\underset{\text{Ethyl aceto acetate}}{CH_3-\overset{O}{\overset{\|}{C}}-CH_2COOC_2H_5} \xrightarrow[\substack{\text{(Phenyl hydrazine)}\\ -H_2O}]{H_2N.NHC_6H_5} \underset{\substack{\text{Ethyl acetoacetate}\\ \text{phenyl hydrazone}}}{CH_3-\overset{N.NHC_6H_5}{\overset{\|}{C}}-CH_2COOC_2H_5}$$

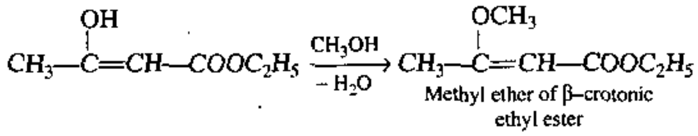
(2) Properties due to enolic form.

(a) 

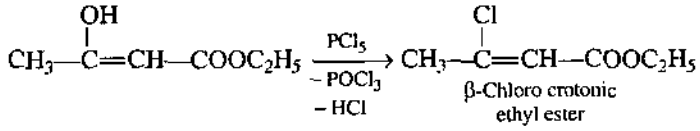
$$\underset{\text{Ethyl acetoacetate}}{CH_3-\overset{OH}{\overset{|}{C}}=CH-COOC_2H_5} \xrightarrow[-H_2O]{NH_3} \underset{\beta\text{-Amino crotonic ester}}{CH_3-\overset{NH_2}{\overset{|}{C}}=CH-COOC_2H_5}$$

(b) 

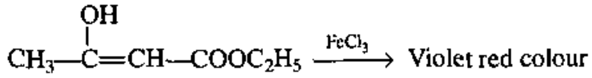
$$CH_3-\overset{OH}{\overset{|}{C}}=CH-COOC_2H_5 \xrightarrow[-HCl]{CH_3COCl} \underset{\text{Acetyl acetoacetic ester}}{CH_3-\overset{OCOCH_3}{\overset{|}{C}}=CH-COOC_2H_5}$$

(c) 

$$CH_3-\overset{OH}{\overset{|}{C}}=CH-COOC_2H_5 \xrightarrow[-H_2O]{CH_3OH} \underset{\substack{\text{Methyl ether of }\beta\text{-crotonic}\\ \text{ethyl ester}}}{CH_3-\overset{OCH_3}{\overset{|}{C}}=CH-COOC_2H_5}$$

(d) 

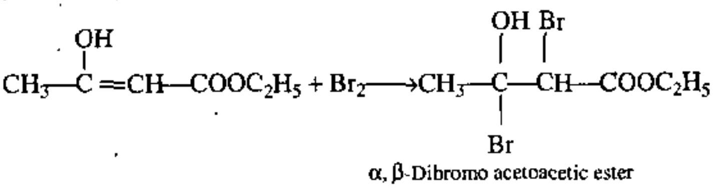
$$CH_3-\overset{OH}{\overset{|}{C}}=CH-COOC_2H_5 \xrightarrow[\substack{-POCl_3\\ -HCl}]{PCl_5} \underset{\substack{\beta\text{-Chloro crotonic}\\ \text{ethyl ester}}}{CH_3-\overset{Cl}{\overset{|}{C}}=CH-COOC_2H_5}$$

(e) 

$$CH_3-\overset{OH}{\overset{|}{C}}=CH-COOC_2H_5 \xrightarrow{FeCl_3} \text{Violet red colour}$$

The violet colour is due to $-\overset{OH}{\overset{|}{C}}=C-$ group.

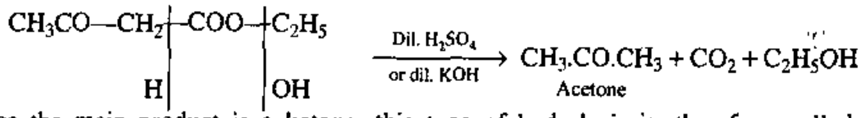
(3) Reaction due to double bond in enolic form.



$$CH_3-\overset{OH}{\overset{|}{C}}=CH-COOC_2H_5 + Br_2 \longrightarrow \underset{\alpha,\beta\text{-Dibromo acetoacetic ester}}{CH_3-\overset{OH}{\overset{|}{\underset{Br}{\underset{|}{C}}}}-\overset{Br}{\overset{|}{CH}}-COOC_2H_5}$$

(4) Hydrolysis : When ethyl acetoacetate is hydrolysed different products are obtained in presence of different hydrolytic agents under different conditions.

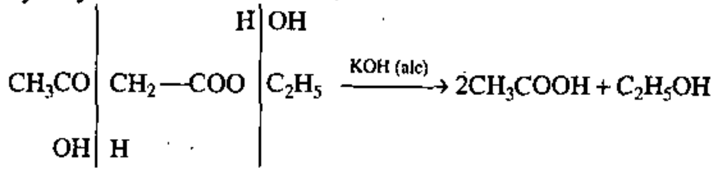
***(i) Ketonic hydrolysis* :** When acetoacetic ester is boiled with dil. H_2SO_4 or baryta or dil. aqueous KOH, it is hydrolysed into a ketone, CO_2 and alcohol.



$$CH_3CO-\underset{H}{CH_2}\Big|-COO-\Big|\underset{OH}{C_2H_5}\xrightarrow[\text{or dil. KOH}]{\text{Dil. }H_2SO_4}\underset{\text{Acetone}}{CH_3.CO.CH_3}+CO_2+C_2H_5OH$$

Since the main product is a ketone, this type of hydrolysis is, therefore, called, *ketonic hydrolysis.*

(ii) Acid hydrolysis : When acetoacetic ester is boiled with concentrated alcoholic KOH or NaOH, it is hydrolysed into an acid and ethanol.



$$\underset{OH}{CH_3CO}\,\Big|\,\underset{H}{CH_2}-\overset{H}{COO}\,\Big|\,\overset{OH}{C_2H_5}\xrightarrow{\text{KOH (alc)}}2CH_3COOH+C_2H_5OH$$

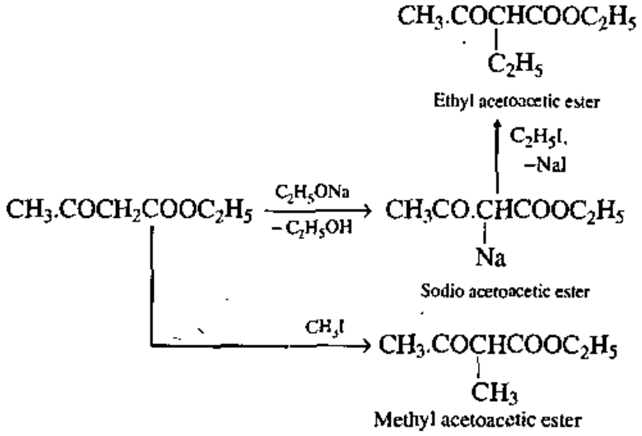
Since the main product is an acid, this type of hydrolysis is called, therefore, *acid hydrolysis.*

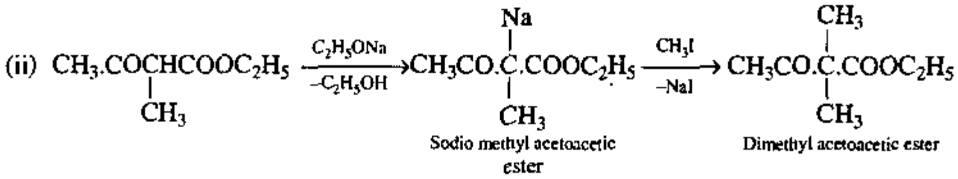
[IV] Synthetic Importance of Acetoacetic Ester

A variety of compounds can be synthesised from acetoacetic ester.

(1) Synthesis of Alkyl Derivatives of Acetoacetic Ester

Monoalkyl esters are formed by the treatment of aceto acetic ester with C_2H_5-O-Na and then with alkyl halide. Dialkyl esters are prepared by treating the above with C_2H_5ONa and alkyl halide.

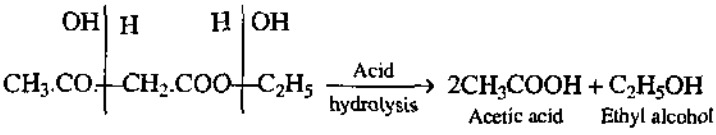




$$\text{(ii)}\ CH_3.CO\underset{CH_3}{\underset{|}{C}}HCOOC_2H_5\xrightarrow[-C_2H_5OH]{C_2H_5ONa}\underset{\text{Sodio methyl acetoacetic ester}}{CH_3CO.\overset{Na}{\overset{|}{\underset{CH_3}{\underset{|}{C}}}}.COOC_2H_5}\xrightarrow[-NaI]{CH_3I}\underset{\text{Dimethyl acetoacetic ester}}{CH_3CO.\overset{CH_3}{\overset{|}{\underset{CH_3}{\underset{|}{C}}}}.COOC_2H_5}$$

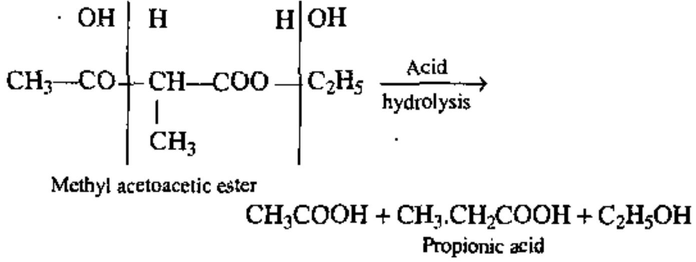
(2) Synthesis of Monobasic Acids

(i) Acetic acid



$$\overset{OH}{CH_3.CO}\Big|\overset{H}{CH_2}.\overset{H}{COO}\Big|\overset{OH}{C_2H_5}\xrightarrow[\text{hydrolysis}]{\text{Acid}}\underset{\text{Acetic acid}}{2CH_3COOH}+\underset{\text{Ethyl alcohol}}{C_2H_5OH}$$

(ii) Propionic acid.

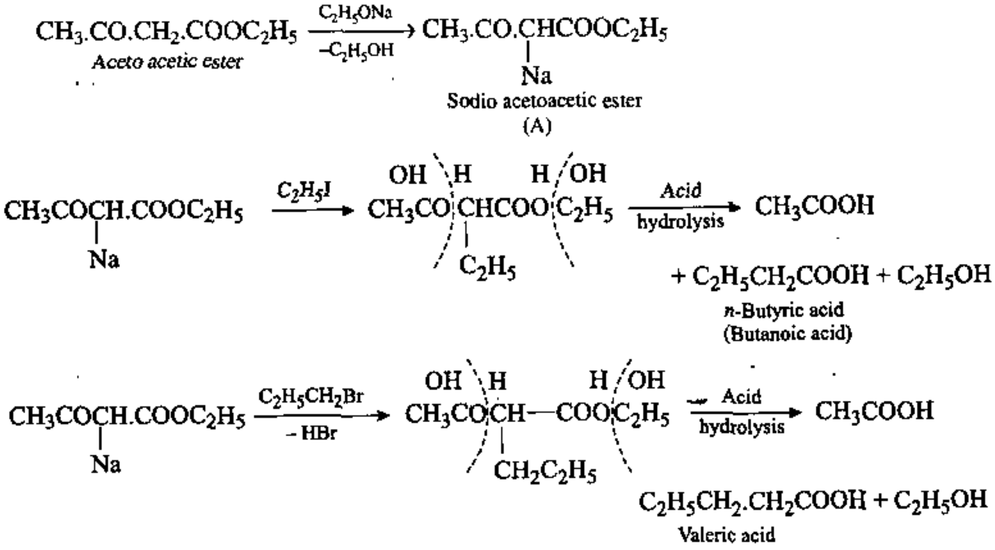


$$\overset{OH}{CH_3-CO}\Big|\overset{H}{\underset{\underset{CH_3}{|}}{CH}}-\overset{H}{COO}\Big|\overset{OH}{C_2H_5}\xrightarrow[\text{hydrolysis}]{\text{Acid}}$$

Methyl acetoacetic ester

$$CH_3COOH+\underset{\text{Propionic acid}}{CH_3.CH_2COOH}+C_2H_5OH$$

(iii) n-Butyric acid and valeric acid.



$$CH_3.CO.CH_2.COOC_2H_5 \xrightarrow[-C_2H_5OH]{C_2H_5ONa} CH_3.CO.\underset{\displaystyle Na}{\underset{|}{C}}HCOOC_2H_5$$

Aceto acetic ester

Sodio acetoacetic ester (A)

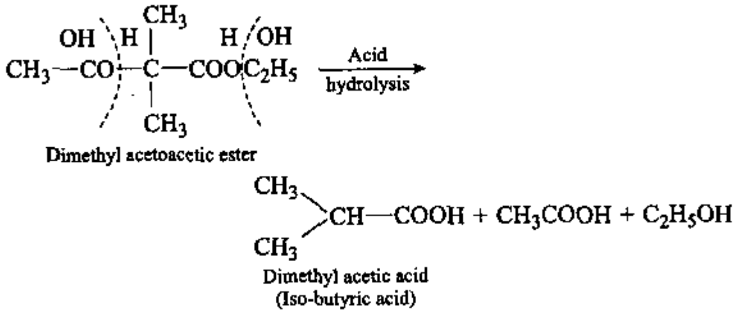
$$CH_3CO\underset{\displaystyle Na}{\underset{|}{C}}H.COOC_2H_5 \xrightarrow{C_2H_5I} CH_3CO\overset{OH\;H}{\vdots}\underset{\displaystyle C_2H_5}{\underset{|}{C}}HCOO\overset{H\;OH}{\vdots}C_2H_5 \xrightarrow[hydrolysis]{Acid} CH_3COOH + C_2H_5CH_2COOH + C_2H_5OH$$

n-Butyric acid (Butanoic acid)

$$CH_3CO\underset{\displaystyle Na}{\underset{|}{C}}H.COOC_2H_5 \xrightarrow[-HBr]{C_2H_5CH_2Br} CH_3CO\overset{OH\;H}{\vdots}\underset{\displaystyle CH_2C_2H_5}{\underset{|}{C}}H-COO\overset{H\;OH}{\vdots}C_2H_5 \xrightarrow[hydrolysis]{Acid} CH_3COOH + C_2H_5CH_2.CH_2COOH + C_2H_5OH$$

Valeric acid

(iv) Dimethyl acetic acid or iso-butyric acid.

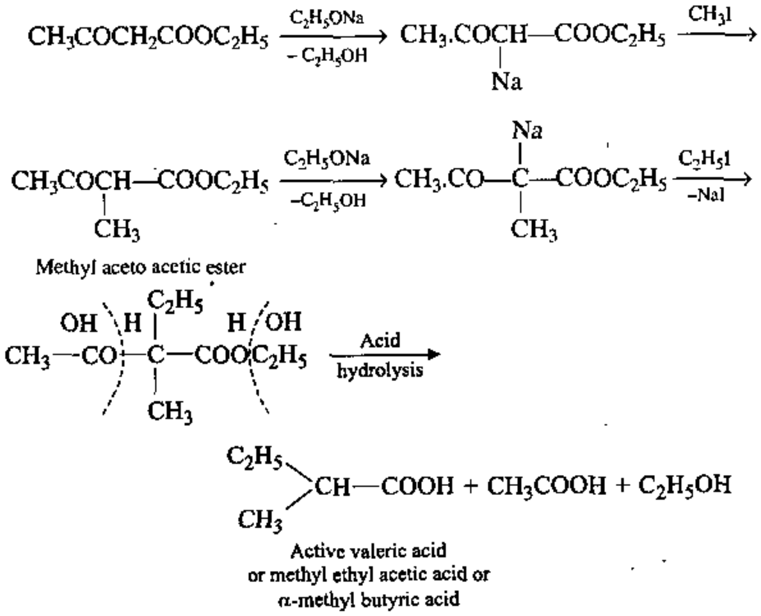


$$CH_3-CO\overset{OH\;H}{\vdots}-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-COO\overset{H\;OH}{\vdots}C_2H_5 \xrightarrow[hydrolysis]{Acid} \begin{matrix}CH_3\\CH_3\end{matrix}\!\!>CH-COOH + CH_3COOH + C_2H_5OH$$

Dimethyl acetoacetic ester

Dimethyl acetic acid (Iso-butyric acid)

(v) Active valeric acid or methyl ethyl acetic acid.



$$CH_3COCH_2COOC_2H_5 \xrightarrow[-C_2H_5OH]{C_2H_5ONa} CH_3.CO\underset{\displaystyle Na}{\underset{|}{C}}H-COOC_2H_5 \xrightarrow{CH_3I}$$

$$CH_3CO\underset{\displaystyle CH_3}{\underset{|}{C}}H-COOC_2H_5 \xrightarrow[-C_2H_5OH]{C_2H_5ONa} CH_3.CO-\overset{\displaystyle Na}{\underset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-COOC_2H_5 \xrightarrow[-NaI]{C_2H_5I}$$

Methyl aceto acetic ester

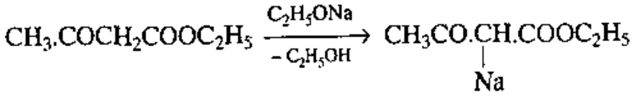
$$CH_3-CO\overset{OH\;H}{\vdots}-\overset{\displaystyle C_2H_5}{\underset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-COO\overset{H\;OH}{\vdots}C_2H_5 \xrightarrow[hydrolysis]{Acid} \begin{matrix}C_2H_5\\CH_3\end{matrix}\!\!>CH-COOH + CH_3COOH + C_2H_5OH$$

Active valeric acid or methyl ethyl acetic acid or α-methyl butyric acid

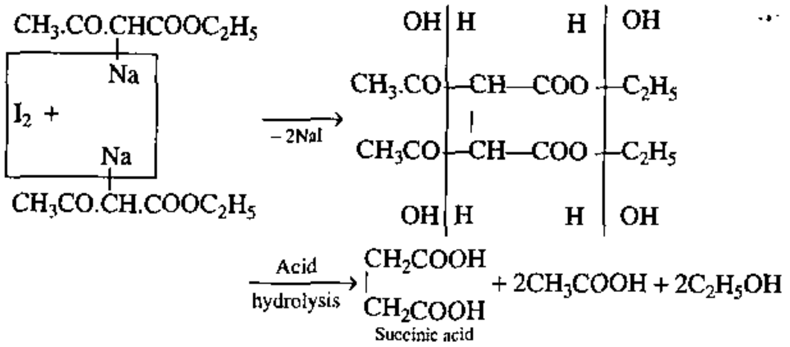
3. Synthesis of Dibasic Acids

(i) Succinic acid.

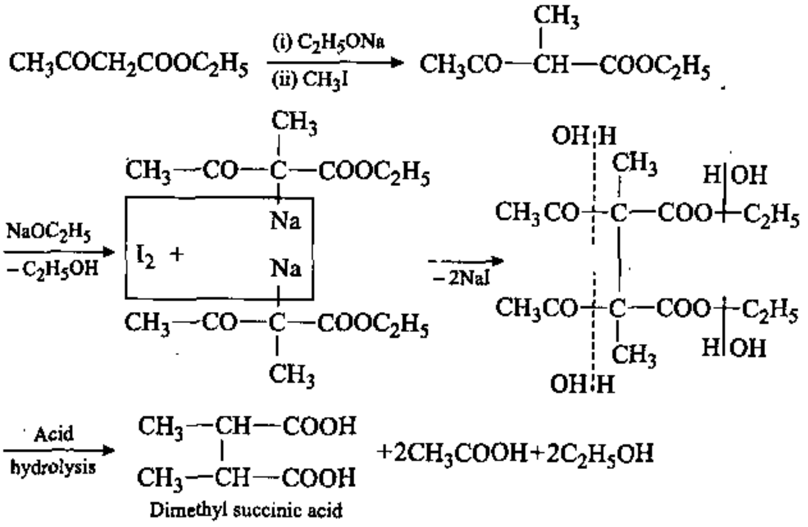
(a)



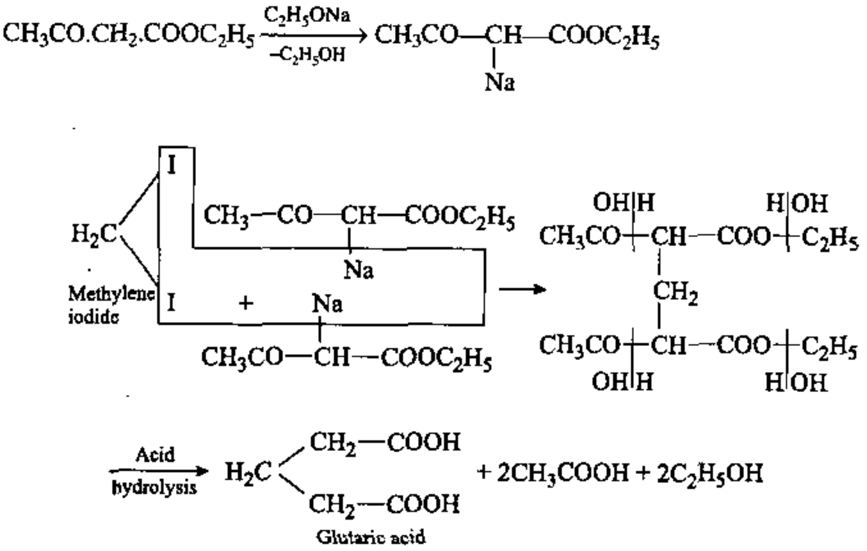
$$CH_3.COCH_2COOC_2H_5 \xrightarrow[-C_2H_5OH]{C_2H_5ONa} CH_3CO.\underset{\displaystyle Na}{\underset{|}{C}}H.COOC_2H_5$$



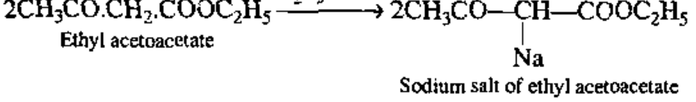
(ii) ***Dimethyl succinic acid.***



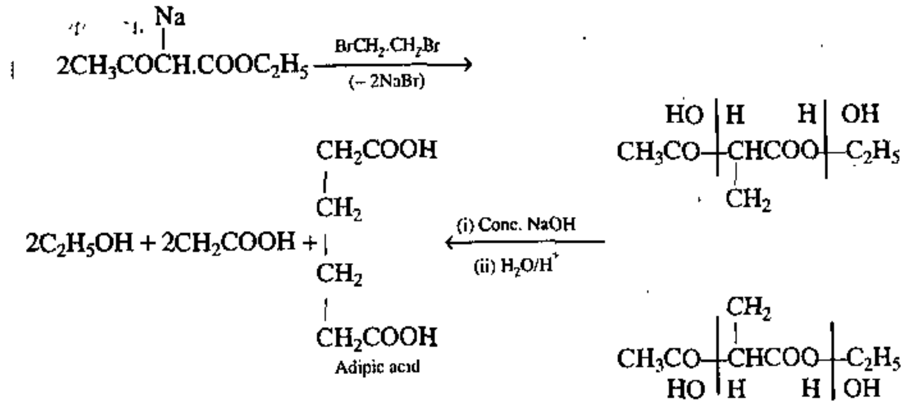
(iii) ***Glutaric acid.***



(iv) Adipic acid : The reaction of sodium acetoacetate (2 molecules with ethylene dibromide) ($BrCH_2.CH_2Br$) followed by acid hydrolysis gives adipic acid (normal dicarboxylic acid).



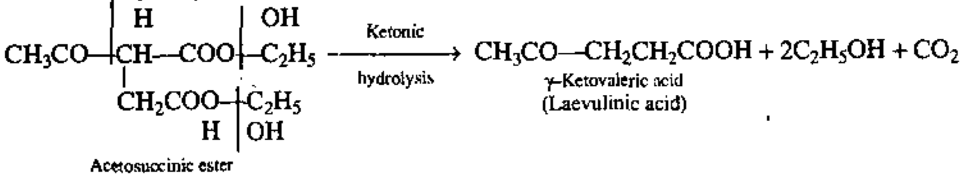
$$\underset{\text{Ethyl acetoacetate}}{2CH_3CO.CH_2.COOC_2H_5} \xrightarrow{C_2H_5ONa} \underset{\text{Sodium salt of ethyl acetoacetate}}{2CH_3CO-\underset{\displaystyle Na}{\underset{|}{C}H}-COOC_2H_5}$$



$$2CH_3CO\overset{Na}{C}H.COOC_2H_5 \xrightarrow[(-\,2NaBr)]{BrCH_2.CH_2Br} \begin{matrix} CH_3CO\text{—}CHCOO\text{—}C_2H_5 \\ | \\ CH_2 \\ | \\ CH_2 \\ | \\ CH_3CO\text{—}CHCOO\text{—}C_2H_5 \end{matrix}$$

$$\xrightarrow[(ii)\ H_2O/H^+]{(i)\ Conc.\ NaOH} 2C_2H_5OH + 2CH_2COOH + \underset{\text{Adipic acid}}{\begin{matrix} CH_2COOH \\ | \\ CH_2 \\ | \\ CH_2 \\ | \\ CH_2COOH \end{matrix}}$$

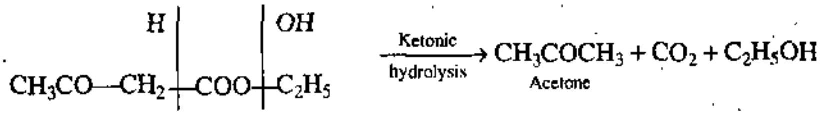
(4) Synthesis of γ-Keto Acids (or Laevulinic acid) : By subjecting acetosuccinic ester as in (3) to ketonic hydrolysis.



$$\underset{\text{Acetosuccinic ester}}{\begin{matrix} CH_3CO\text{—}CH\text{—}COO\text{—}C_2H_5 \\ | \\ CH_2COO\text{—}C_2H_5 \end{matrix}} \xrightarrow[\text{hydrolysis}]{\text{Ketonic}} \underset{\substack{\gamma\text{-Ketovaleric acid} \\ \text{(Laevulinic acid)}}}{CH_3CO\text{—}CH_2CH_2COOH} + 2C_2H_5OH + CO_2$$

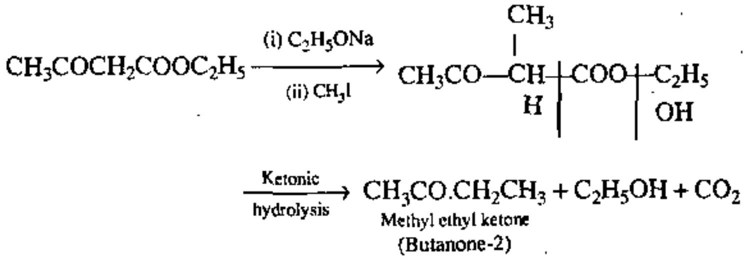
(5) Synthesis of Ketones

(i) Acetone.



$$CH_3CO\text{—}CH_2\text{—}COO\text{—}C_2H_5 \xrightarrow[\text{hydrolysis}]{\text{Ketonic}} \underset{\text{Acetone}}{CH_3COCH_3} + CO_2 + C_2H_5OH$$

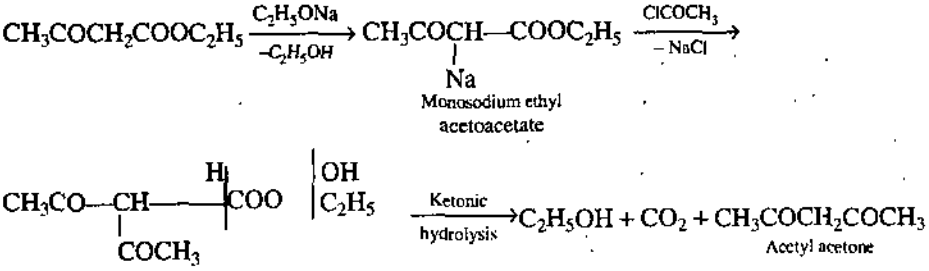
***(ii) Methyl ethyl ketone* (Butanone–2)**



$$CH_3COCH_2COOC_2H_5 \xrightarrow[(ii)\ CH_3I]{(i)\ C_2H_5ONa} CH_3CO\text{—}\overset{CH_3}{\underset{H}{C}}\text{—}COO\text{—}C_2H_5$$

$$\xrightarrow[\text{hydrolysis}]{\text{Ketonic}} \underset{\substack{\text{Methyl ethyl ketone} \\ \text{(Butanone-2)}}}{CH_3CO.CH_2CH_3} + C_2H_5OH + CO_2$$

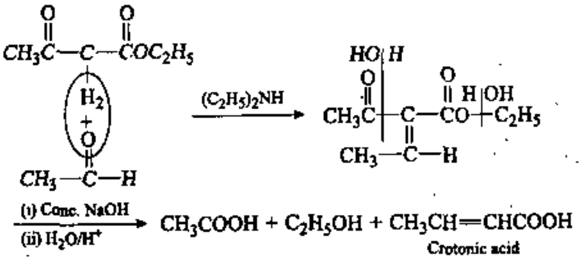
(6) Synthesis of Diketones (or Acetylacetone).



$$CH_3COCH_2COOC_2H_5 \xrightarrow[-C_2H_5OH]{C_2H_5ONa} \underset{\substack{\text{Monosodium ethyl} \\ \text{acetoacetate}}}{CH_3CO\underset{Na}{C}H\text{—}COOC_2H_5} \xrightarrow[-\,NaCl]{ClCOCH_3}$$

$$CH_3CO\text{—}\underset{COCH_3}{C}H\text{—}COO\text{—}C_2H_5 \xrightarrow[\text{hydrolysis}]{\text{Ketonic}} C_2H_5OH + CO_2 + \underset{\text{Acetyl acetone}}{CH_3COCH_2COCH_3}$$

(7) Synthesis of Unsaturated Acids : If the product obtained by the condensation of ethyl acetoacetate or its derivatives with an aldehyde is subjected to acid hydrolysis, unsaturated acids are formed.

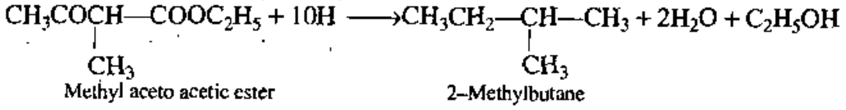


$$CH_3\overset{O}{\overset{\|}{C}}\text{—}\underset{H_2}{C}\text{—}\overset{O}{\overset{\|}{C}}OC_2H_5 + \overset{O}{\overset{\|}{CH_3\text{—}C\text{—}H}} \xrightarrow{(C_2H_5)_2NH} CH_3\overset{O}{\overset{\|}{C}}\text{—}\underset{CH_3\text{—}C\text{—}H}{\underset{\|}{C}}\text{—}\overset{O}{\overset{\|}{C}}O\text{—}C_2H_5$$

$$\xrightarrow[(ii)\ H_2O/H^+]{(i)\ Conc.\ NaOH} CH_3COOH + C_2H_5OH + \underset{\text{Crotonic acid}}{CH_3CH{=}CHCOOH}$$

(8) Synthesis of Hydrocarbons : The ester and its alkyl derivatives form paraffins on electrolytic reduction.

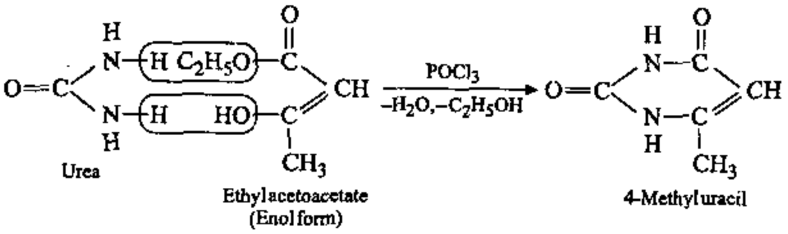
$$CH_3COCH_2COOC_2H_5 + 10H \longrightarrow \underset{n\text{–Butane}}{CH_3CH_2CH_2CH_3} + 2H_2O + C_2H_5OH$$



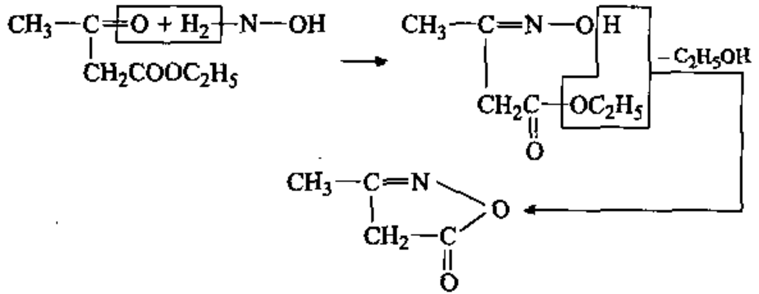
$$\underset{\text{Methyl aceto acetic ester}}{CH_3CO\underset{CH_3}{\underset{|}{C}}H—COOC_2H_5} + 10H \longrightarrow \underset{\text{2–Methylbutane}}{CH_3CH_2—\underset{CH_3}{\underset{|}{C}}H—CH_3} + 2H_2O + C_2H_5OH$$

(9) Synthesis of Heterocyclic Compounds

(i) Ethyl acetoacetate (in its enol form) reacts with urea in presence of phosphoryl chloride to form 4-methyl uracil.

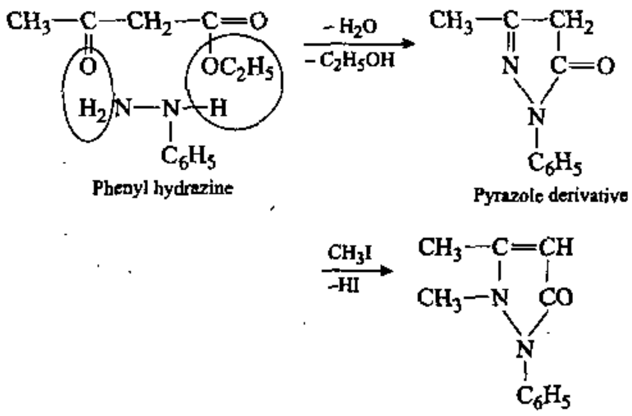


(ii) With hydroxylamine ethyl acetoacetate gives methyl iso-oxazolone.



Methyliso-oxazolone

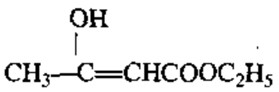
(iii) With phenyl hydrazine, ethyl acetoacetate gives pyrazole derivative which gives antipyrine with CH_3I.



Antipyrine

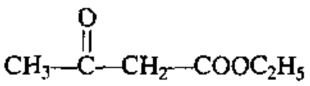
[V] Structure of Ethyl Acetoacetate

Geuther (1863), Frankland and Duppa (1865) prepared acetoacetic ester independent of each other and proposed the following two structures for it :



$$CH_3—\overset{OH}{\overset{|}{C}}=CHCOOC_2H_5$$

Geuther formula, Enol form
(β–Hydroxy crotonic ester)



$$CH_3—\overset{O}{\overset{\|}{C}}—CH_2—COOC_2H_5$$

Frankland–Duppa formula,
Keto form
(β–Keto butyric ester)

It started a controversy and the evidences in support of both the structures were forwarded as given below :

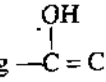
(1) The molecular formula of ethyl acetoacetate is $C_6H_{10}O_3$.

(2) Evidences in support of Geuther formula

(a) Ethyl acetoacetate reacts with metallic sodium to form sodio-derivative with the evolution of H_2.

(b) Ethyl acetoacetate forms acetyl derivative with CH_3COCl showing the presence of an alcoholic group.

(c) Ethyl acetoacetate is neutral to litmus but dissolves in alkalies showing the presence of an acidic —OH group, as in phenols.

(d) Ethyl acetoacetate produces reddish-violet colour with $FeCl_3$. This is characteristic of compounds containing  $-\overset{\overset{\displaystyle OH}{|}}{C}=CH$, *i.e.*, enolic group.

(e) Ethyl acetoacetate gives an addition product with bromine showing the presence of an ***olefinic double bond.***

(f) When treated with ammonia, ethyl acetoacetate forms β-amino crotonic ester. This shows the presence of —OH group on the β-carbon in the ester. Thus, it may be regarded as β-hydroxy crotonic ester as suggested by Geuther.

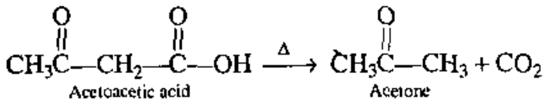
(3) Evidences in support of Frankland-Duppa formula

(a) Ethyl acetoacetate forms cyanohydrin with HCN and bisulphite compound with $NaHSO_3$.

(b) Ethyl acetoacetate forms an oxime with hydroxylamine and a phenyl hydrazone with *phenyl hydrazine.*

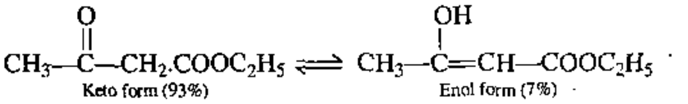
(c) On reduction with sodium amalgam or with lithium aluminium hydride in pyridine, ethyl *acetoacetate gives β-hydroxy butyric ester containing a* ***secondary alcoholic group.***

(d) When ethyl acetoacetate is hydrolysed with dil. NaOH solution in cold, acidified and extracted with ether, it forms crystalline acetoacetic acid (Krueger, 1952). This on heating yields acetone showing thereby that acetoacetic acid is a ***β-keto acid*** and ethyl acetoacetate is a ***β-keto ester.***



$$\underset{\text{Acetoacetic acid}}{CH_3\overset{\overset{\displaystyle O}{\|}}{C}-CH_2-\overset{\overset{\displaystyle O}{\|}}{C}-OH} \xrightarrow{\Delta} \underset{\text{Acetone}}{CH_3\overset{\overset{\displaystyle O}{\|}}{C}-CH_3} + CO_2$$

(4) Modern view : It has been assumed that ordinary ester exists as a tautomeric mixture of both enolic and ketonic forms, which is an example of keto-enol tautomerism.



$$\underset{\text{Keto form (93\%)}}{CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-CH_2.COOC_2H_5} \rightleftharpoons \underset{\text{Enol form (7\%)}}{CH_3-\overset{\overset{\displaystyle OH}{|}}{C}=CH-COOC_2H_5}$$

(5) Confirmation : The existence of both forms in ordinary ester has been confirmed by Knorr. He separated both the varieties from the ordinary ester.

Keto form (MP = –39°C) was obtained by cooling the ester in light petrol at –78°C. Enol form was obtained by treating sodio derivative of ester with HCl at –78°C in light petrol. The existence of these two forms has been supported by molecular refraction and other physical properties.

• 5.5. CLAISEN CONDENSATION

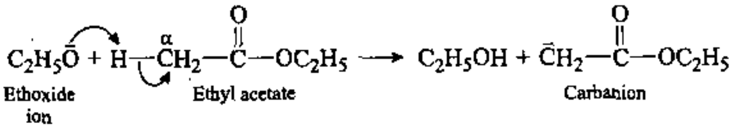
Claisen (1887) observed that when esters having hydrogens at α-carbon atoms are treated with sodium alkoxides, they form β-keto esters. ***The condensation between two molecules of esters having α-hydrogen atoms, in the presence of a fase resulting in the formation of a compound having reactive methylene group is known as Claisen condensation.*** The following mechanism is suggested for Claisen condensarion.

(1) Reaction of sodium with ethyl alcohol gives ethoxide ion which acts as a base.

$$2C_2H_5OH + 2Na \longrightarrow 2C_2H_5ONa + H_2$$

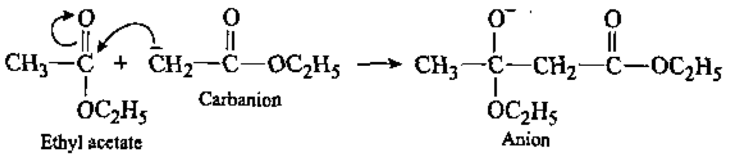
$$C_2H_5ONa \rightleftharpoons \underset{\text{Ethoxide ion}}{C_2H_5O^-} + Na^+$$

(2) The ethoxide ion so formed, abstracts a proton from the α-carbon of the ester like ethyl acetate to form a carbanion.



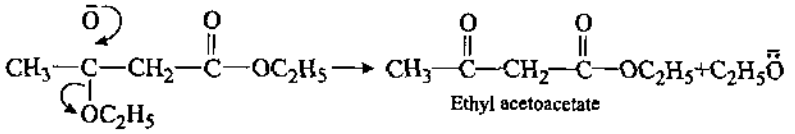
$$\underset{\text{Ethoxide ion}}{C_2H_5\bar{O}} + \underset{\text{Ethyl acetate}}{H-\overset{\alpha}{C}H_2-\overset{\overset{\displaystyle O}{\|}}{C}-OC_2H_5} \longrightarrow C_2H_5OH + \underset{\text{Carbanion}}{\bar{C}H_2-\overset{\overset{\displaystyle O}{\|}}{C}-OC_2H_5}$$

(3) This carbanion induces the electromeric shift in the carbonyl group of other ester molecule.



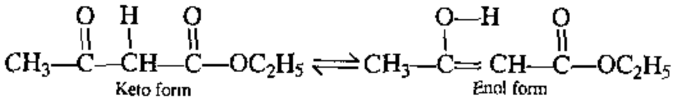
$$CH_3-\underset{OC_2H_5}{\overset{O}{\overset{\|}{C}}} + \bar{C}H_2-\overset{O}{\overset{\|}{C}}-OC_2H_5 \longrightarrow CH_3-\underset{OC_2H_5}{\overset{O^-}{\overset{|}{C}}}-CH_2-\overset{O}{\overset{\|}{C}}-OC_2H_5$$

(4) As the attacking reagent, *i.e.*, carbanion is removed by addition, the electron pair which had shifted to oxygen because of electromeric effect, reverts back to form a double bond and the ethoxide ion is given out with its pair of electrons.



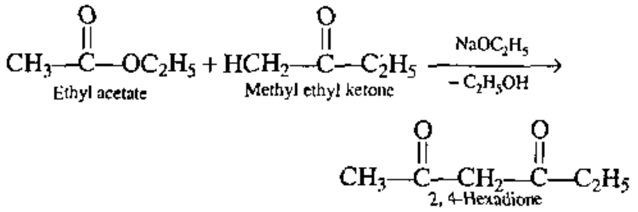
$$CH_3-\underset{OC_2H_5}{\overset{\bar{O}}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OC_2H_5 \longrightarrow CH_3-\overset{O}{\overset{\|}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OC_2H_5 + C_2H_5\bar{O}$$

On acidification with CH_3COOH, ethyl acetoacetate is converted to tautomeric mixture of two forms of ethyl acetoacetate.



$$CH_3-\overset{O}{\overset{\|}{C}}-\overset{H}{\overset{|}{C}}H-\overset{O}{\overset{\|}{C}}-OC_2H_5 \rightleftharpoons CH_3-\overset{O-H}{\overset{|}{C}}=CH-\overset{O}{\overset{\|}{C}}-OC_2H_5$$

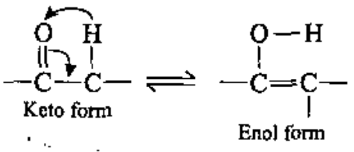
Claisen condensation can be carried out between different esters also when a mixture of different products is formed. The reaction may also be extended to condensations between esters and carbonyl compounds like ketones etc. Therefore,



$$CH_3-\overset{O}{\overset{\|}{C}}-OC_2H_5 + HCH_2-\overset{O}{\overset{\|}{C}}-C_2H_5 \xrightarrow[-\,C_2H_5OH]{NaOC_2H_5} CH_3-\overset{O}{\overset{\|}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-C_2H_5$$

5.6. KETO-ENOL TAUTOMERISM

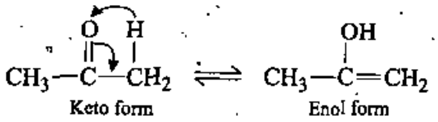
When two structural isomers are mutually interconvertible and exist in dynamic equilibrium they are known as ***tautomers*** and the phenomenon is called ***tautomerism***. For example, acetone shows tautomerism and may be represented as an equilibrium mixture of two isomers.



$$-\overset{O}{\overset{\|}{C}}-\overset{H}{\overset{|}{C}}- \rightleftharpoons -\overset{O-H}{\overset{|}{C}}=\underset{|}{C}-$$

In the above case, the keto form changes to the enol form due to migration of a proton to carbonyl oxygen. Then a pair of electron shifts from the C—H bond to C—C bond.

Aldehydes, ketones and other carbonyl compounds, *e.g.*, esters show keto-enol tautomerism. It involves the migration of a proton (H^+) from α-carbon to carbonyl oxygen by the following mechanism.

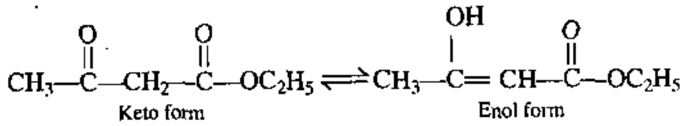


$$CH_3-\overset{O}{\overset{\|}{C}}-\overset{H}{\overset{|}{C}}H_2 \rightleftharpoons CH_3-\overset{OH}{\overset{|}{C}}=CH_2$$

The tautomer containing the carbonyl group (C = O) is designated as the **keto form**. The other tautomer containing a hydroxy group attached to a doubly bonded carbon is designated as the **enol form** (alk ENe + alcohOL). This type of tautomerism is known as keto-enol tautomerism.

[I] Keto-Enol Tautomerism of Ethyl Acetoacetate

Ethyl acetoacetate is a classical example of keto-enol tautomerism.



$$CH_3-\overset{O}{\overset{\|}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OC_2H_5 \rightleftharpoons CH_3-\overset{OH}{\overset{|}{C}}=CH-\overset{O}{\overset{\|}{C}}-OC_2H_5$$

Keto form Enol form

Geuther (1863) gave the keto structure, while Frankland and Duppa (1865) gave the enol structure to ethyl acetoacetate.

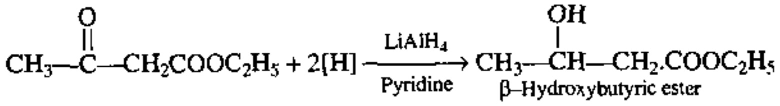
(a) Reactions supporting the keto form

(1) Ethyl acetoacetate forms a bisulphite compound with sodium hydrogen sulphite.

(2) Ethyl acetoacetate forms an oxime with hydroxyl amine and phenylhydrazone with phenylhydrazine.

(3) Ethyl acetoacetate forms a cyanohydrin with HCN.

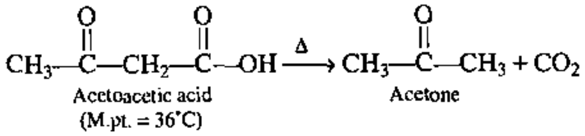
(4) On reduction with sodium amalgam or by using $LiAlH_4$ in pyridine, ethyl acetoacetate gives β-hydroxybutyric ester containing a secondary alcoholic group.



$$CH_3-\overset{O}{\overset{\|}{C}}-CH_2COOC_2H_5 + 2[H] \xrightarrow[\text{Pyridine}]{LiAlH_4} CH_3-\overset{OH}{\overset{|}{C}H}-CH_2.COOC_2H_5$$

β-Hydroxybutyric ester

(5) On hydrolysis with dil. NaOH in cold, acidified and extracted with ether, ethyl acetoacetate forms a crystalline acetoacetic acid (Kruger 1952). This compound on heating gives acetone. This shows that aceto acetic acid is a β-keto acid and ethyl acetoacetate a β-keto ester.



$$CH_3-\overset{O}{\overset{\|}{C}}-CH_2-\overset{O}{\overset{\|}{C}}-OH \xrightarrow{\Delta} CH_3-\overset{O}{\overset{\|}{C}}-CH_3 + CO_2$$

Acetoacetic acid (M.pt. = 36°C) Acetone

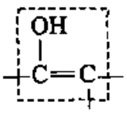
(b) Reactions supporting the enol form

(1) Ethyl acetoacetate reacts with sodium metal to form the sodio derivative and hydrogen gas is evolved. This shows the presence of OH group.

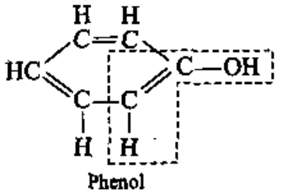
(2) Ethyl acetoacetate forms an acetyl derivative with acetyl chloride which indicates the presence of OH group.

(3) On treating ethyl acetoacetate *with alcoholic bromine solution, the brown colour of the* latter is discharged. This shows the presence of an alkene double bond (C=C).

(4) With $FeCl_3$, ethyl acetoacetate forms a reddish violet colour. This reaction is characteristic *of enolic OH group. This points to the presence of C=C—OH structural unit in ethyl acetoacetate* as in phenols.



Enolic OH



Phenol

SUMMARY

- A methylene group (—CH_2—) which is directly bonded to two electron withdrawing groups such as —$COCH_3$, —$COOC_2H_5$ is known as a reactive methylene group.
- Ethyl acetoacetate contains a methylene group joined to two carbonyl groups. The C—H bond in —CH_2 group is readily ionisable because the proton removal forms a very stable carbanion.
- The acidity of the C—H bond of methylene group is due to inductive effect and resonance stabilisation of carbanion.
- The condensation between two molecules of esters having α-hydrogen atoms, in presence of a base, results in the formation of a compound having a reactive methylene group. This is known as *Claisen condensation.*
- Two structural isomers which are mutually interconvertible and exist in dynamic equilibrium are known as **tantomers**. This phenomenon is known as **tantomerism**.
- *The tautomer containing* the carbonyl group (>C=O) is designated as the keto form.
- The tautomer containing a hydroxyl group attached to a doubly bonded carbon is designated as the enol form. The tautomerism of keto and enol forms is known as keto-enol tautomerism.

• STUDENT ACTIVITY

1. Define a reactive methylene group with examples.

2. Discuss the acidity of α-hydrogens in diethyl malonate.

3. Write a short note on Claisen condensation with its mechanism.

4. How will you obtain succinic acid from ethyl acetoacetate ?

• TEST YOURSELF

1. What is a reactive methylene group ? Discuss the characteristics and synthetic importance of compounds containing such a group.
2. Explain the acidity of α-hydrogens in a reactive methylene compound.
3. Describe the alkylation of diethyl malonate and ethyl acetoacetate.
4. Describe the preparation and synthetic uses of diethyl malonate.
5. Describe the preparation and synthetic uses of ethyl acetoacetate.
6. Starting from diethyl malonate, how will obtain the following compounds ?

(i) Acetic acid	(ii) Propionic acid	(iii) *n*-Butyric acid
(iv) Succinic acid	(v) Glutaric acid	(vi) Adipic acid
(vii) Glycine	(viii) Crotonic acid	(ix) Cinnamic acid

(x) Barbituric acid (xi) Cyclopropane (xii) Acetone.

7. Starting from acetoacetic ester, how will you obtain the following compounds ?
   (i) Laevulinic acid (ii) Acetone (iii) Propionic acid
   (iv) Acetic acid (v) Butanoic acid (vi) Succinic acid
   (vii) Glutaric acid (viii) Adipic acid (ix) Crotonic acid
   (x) An oxazolone derivative (xi) Antipyrine
8. *Discuss the structure of ethyl acetoacetate.*
9. Write a note on Claisen condensation including its mechanism.
10. What is keto-enol tautomerism ? Discuss this tautomerism in ethyl acetoacetate.
11. *How will you convert acetoacetic ester into malonic ester and vice versa ?*
12. Which of the following is not a reactive methylene group compound ?
    (a) Ethyl acetoacetate (b) Acetone (c) Diethyl malonate (d) Cyanoacetic ester
13. Malonic ester on hydrolysis and heating gives :
    (a) Acetic acid (b) Malonic acid (c) Succinic acid (d) Propanoic acid
14. Sodio derivative of acetoacetic ester on heating with iodine gives a compound which on hydrolysis gives :
    (a) Adipic acid (b) Malonic acid (c) Glutaric acid (d) Succinic acid
15. Sodio derivative of acetoacetic ester reacts with ethylene dibromide to give a product which on hydrolysis gives :
    (a) Succinic acid (b) Crotonic acid (c) Adipic acid (d) Cinnamic acid

16. Fill in the blanks :

(i) In reactive methylene group compounds, the methylene group is situated between two electron .... groups.

(ii) Acetoacetic ester shows the properties of .... group as well as of .... group.

(iii) The condensation of two molecules of esters having α-hydrogen atoms in the presence of a base to form a reactive methylene group compound is known as .... condensation.

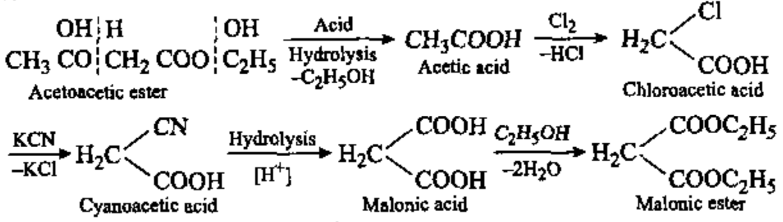
(iv) Malonic ester reacts with urea in presence of $POCl_3$ *to give............*

(v) Ethyl malonic ester on hydrolysis and heating gives ....

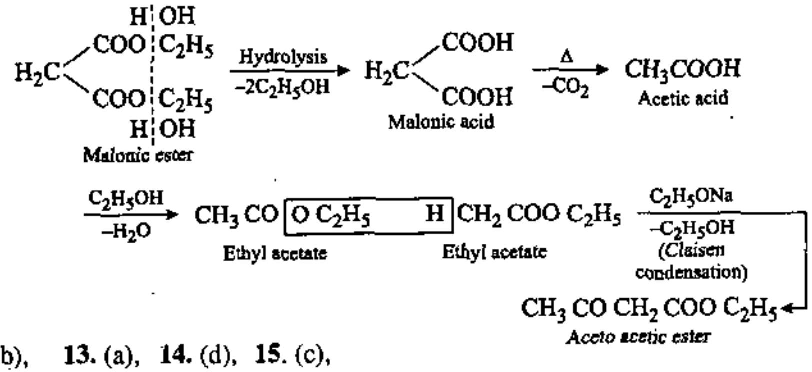
ANSWERS

11.

(i) Acetoacetic ester into malonic ester



(ii) Malonic ester into acetoacetic ester



12. (b), **13.** (a), **14.** (d), **15.** (c),

16. (i) withdrawing (ii) ketonic, enolic (iii) Claisen (iv) barbituric acid, (v) *n*-butyric acid.

UNIT

6

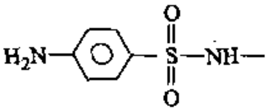
SULPHA DRUGS

LEARNING OBJECTIVES

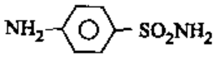
- **Sulpha Drugs and Their Mechanism**
- **Sulphacetamide**
- **Sulphaguanidine**
- **Sulphapyridine**
- **Sulphadiazine**
- **Sulphathiazole**
- **Sulphamethazine**
  - **Summary**
  - **Student Activity**
  - **Test Yourself**

• 6.1. SULPHA DRUGS AND THEIR MECHANISM

A drug may be defined as a substance used in the diagnosis, prevention and cure of disease in human being or other animals. It may be a single chemical substance or a combination of two or more different chemical substances. The structural unit in all sulphadrugs is sulphanilamido group, *i.e.,*



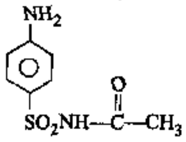
Thus, a group of drugs which are the derivatives of sulphanilamide are called as sulpha drugs *i.e.,*



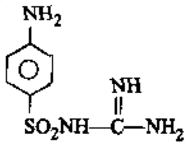
Sulphanilamide
(*p*-amino benzene sulphonamide)

Sulpha drugs have great antibacterial power and are much effective against diseases such as dysentry, pneumonia, diptheria, tuberculosis etc. When these drugs are given to the patients, the bacteria absorb them and their growth is checked. Now a days more effective antibiotics are used for most of the bacterial diseases in place of sulpha drugs.

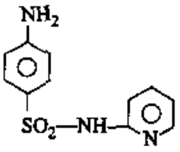
Some of the important sulpha drugs are :



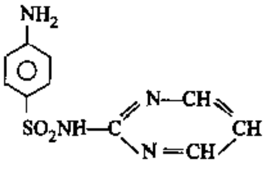
Sulphacetamide



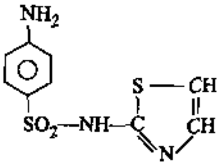
Sulphaguanidine



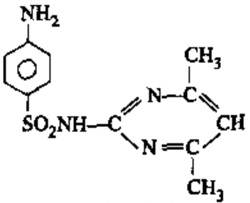
Sulphapyridine



Sulphadiazine



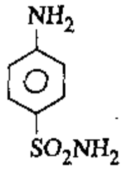
Sulphathiazole



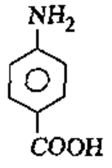
Sulphamethazine

Mechanism of Action of Sulpha Drugs

The drugs which reduce the growth of micro-organisms are called antimetabolites. Sulpha drugs act as antimetabolites and reduce the growth of bacteria. Para amino benzoic acid (PABA) is an essential nutrient for the bacteria which are sensitive to sulphadrugs. Certain enzymes present in these bacteria require PABA for the synthesis of folic acid (a member of vitamin B complex). The sulphanilamide derivatives check the activity of enzymes involved in the synthesis of folic acid. The structure of sulphanilamide is similar to that of *p*-amino benzoic acid.



Sulphanilamide

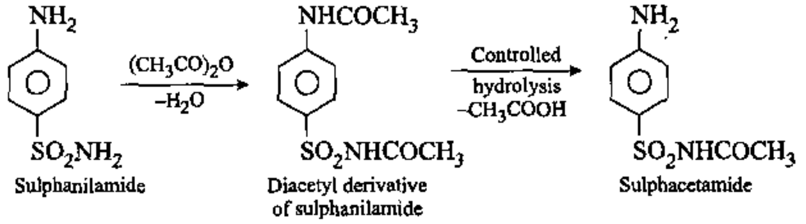


p-Aminobenzoic acid (PABA)

When sulphanilamide is given to a patient suffering from bacterial infection, bacteria take up sulphanilamide instead of PABA. This occurs because bacterial enzymes are not able to distinguish between sulphanilamide and PABA. Sulphanilamide does not work as PABA and thus, reduces the activity of enzymes present in these bacteria. Thus, the synthesis of folic acid is checked. In this way, sulpha drugs check the growth and reproduction of bacteria.

6.2. SULPHACETAMIDE (N′-ACETYL SULPHANILAMIDE OR ACETAMIDE)

Synthesis : Sulphacetamide is prepared by the careful and controlled hydrolysis of the diacetyl derivative of sulphanilamide.

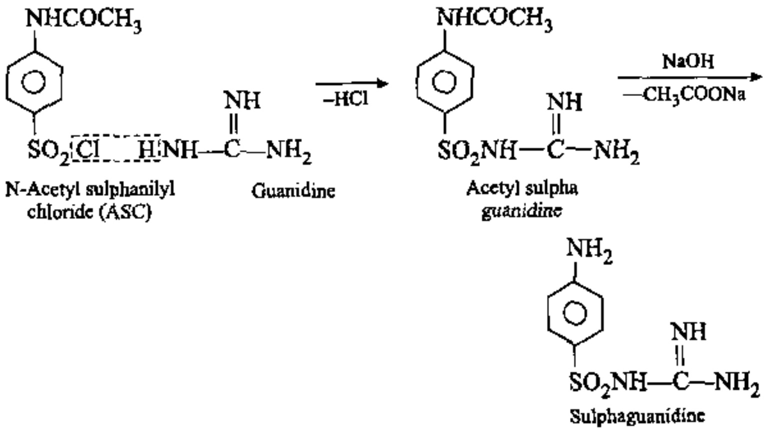


Sulphacetamide is highly water soluble drug and is used for urinary tract infections but due to its toxic nature, it is replaced by other highly soluble sulpha drug sulphisoxazole.

6.3. SULPHAGUANIDINE

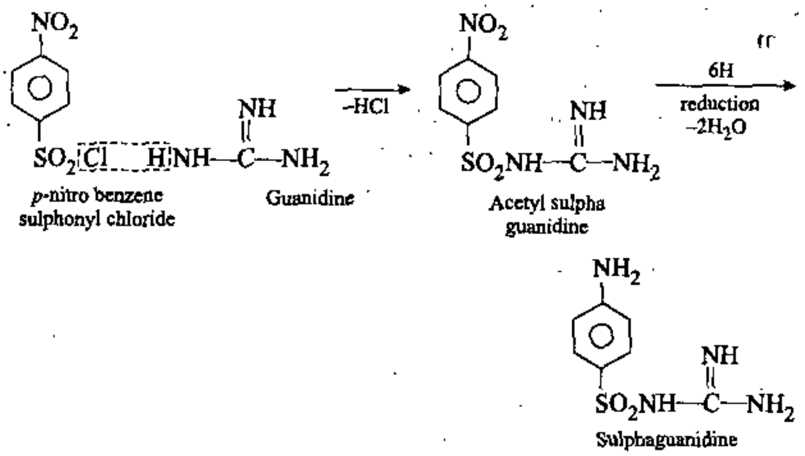
Synthesis : Sulphaguanidine is prepared :

(i) By the condensation of N-acetyl sulphanilyl chloride (ASC) with guanidine. The resulting product is hydrolysed by an alkali when sulphaguanidine is obtained.



(ii) By the condensation of *p*-nitro benzene sulphonyl chloride with guanidine followed by the reduction of nitro group.

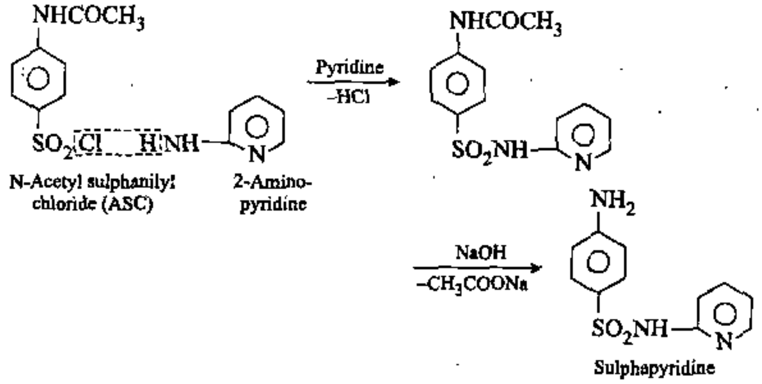
Sulphaguanidine is a white crystalline solid M.Pt. 196°C. It is less soluble in cold water but is more soluble in hot water. It is absorbed by intestine and is used as medicine in dysentry.



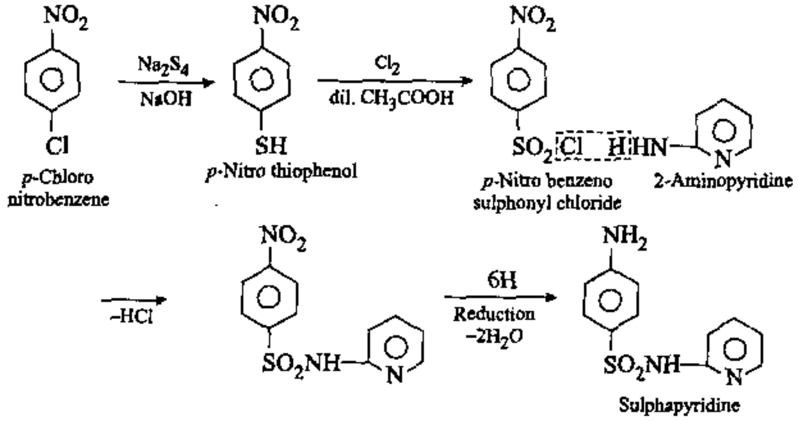
6.4. SULPHAPYRIDINE (N′-2 PYRIDYL SULPHANILAMIDE)

Synthesis : Sulphapyridine is prepared :

(i) By the condensation of N-Acetyl sulphanilyl chloride (ASC) with 2-amino pyridine in the presence of pyridine. The resulting product is hydrolysed by an alkali when sulphapyridine is obtained.



(ii) From p-chloronitrobenzene

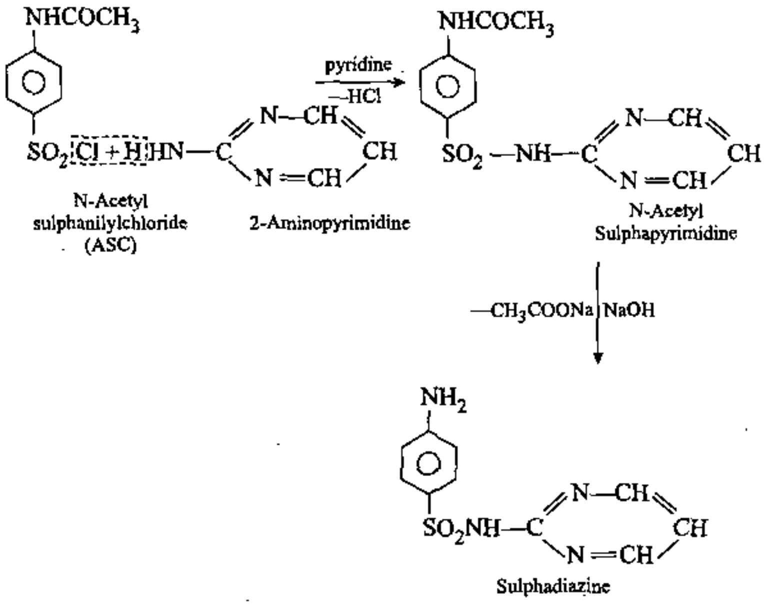


Sulphapyridine is used to cure pneumonia.

6.5. SULPHADIAZINE OR SULPHA-PYRIMIDINE (N′-2-PYRIMIDYL SULPHANILAMIDE)

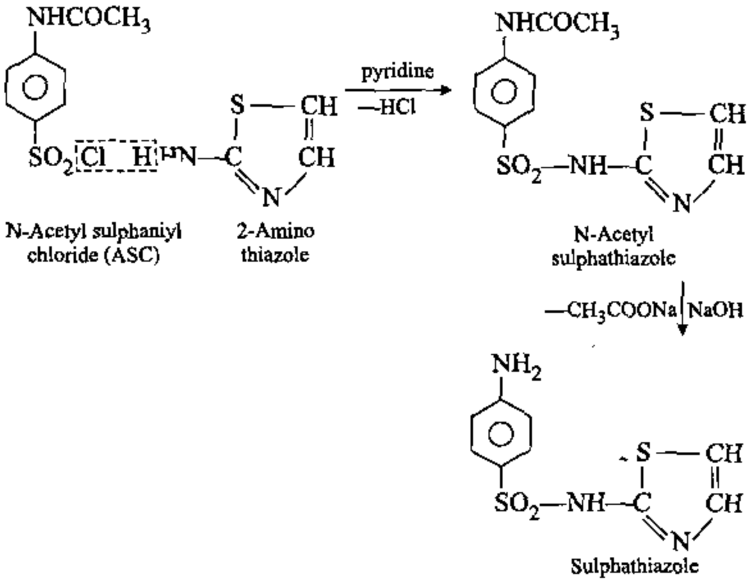
Synthesis : Sulphadiazine is prepared by the condensation of N-Acetyl sulphanilyl chloride (ASC) with 2-Amino pyrimidine in the presence of pyridine. The resulting product is hydrolysed by an alkali when sulphadiazine is obtained.

Sulphadiazine is white powder, M.Pt. 252–256°C. It is soluble in hot water, mineral acids and NaOH but it is insoluble in chloroform and ether. It is used to cure pneumonia, throat infections etc.



6.6. SULPHATHIAZOLE OR CIBAZOLE (N′-2-THIAZOLYL SULPHANILAMIDE)

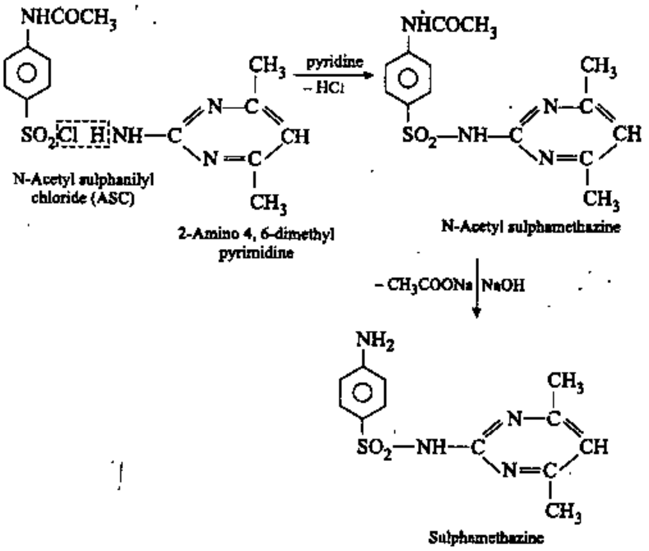
Synthesis : Sulphathiazole is prepared by the condensation of *N*-Acetyl sulphanilyl chloride (ASC) with 2-Amino thiazole in the presence of pyridine. The product is hydrolysed by an alkali when sulphathiazole is obtained.



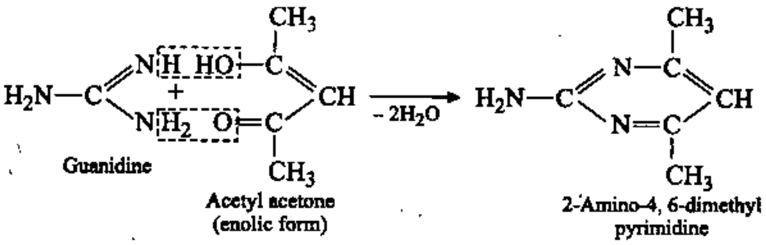
Sulphathiazole is about fifty times more effective than sulphanilamide and is relatively less toxic. It is used in severe infections.

6.5. SULPHAMETHAZINE OR SULPHAMEZATHINE OR N′-2 (4, 6-DIMETHYL PYRIMIDYL SULPHANILAMIDE)

Synthesis : Sulphamethazine is prepared by the condensation of N-Acetyl sulphanilyl chloride (ASC) with 2-Amino 4, 6-dimethyl pyrimidine in the presence of pyridine. The resulting product is hydrolysed by an alkali when sulphamethazine is obtained.



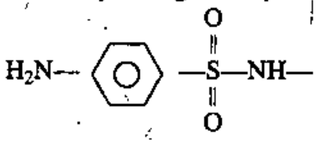
2-Amino-4, 6 dimethylpyrimidine required above may be prepared by the condensation of acetyl acetone with guanidine.



Sulphamethazine is used for general purposes.

SUMMARY

- A drug is a substance which is used in the diagnosis, prevention and cure of disease in human beings or other animals.
- The structural unit in all sulpha drigs is sulphanilamido group, *i.e.*,



$$H_2N-C_6H_4-\overset{O}{\underset{O}{\overset{\|}{\underset{\|}{S}}}}-NH-$$

- A group of drugs which are derivatives of sulphanilamide are known as sulpha drugs.
- Sulpha drugs have great antibacterial power and are much effective against diseases like dysentry, pneumonia, diptheria, tuberculosis etc.
- Sulphacetamide is used for urinary tract infections, but due to its toxic nature, it is replaced by other highly soluble sulpha drug, sulphisoxazole.
- Sulphaguanidine is used as a medicine in dysentry.
- Sulphadiazine is used to cure pneumonia and throat infections etc.

STUDENT ACTIVITY

1. What are sulpha drugs ?

What is the use of sulphaguanidine ?

3. Write the synthesis of sulphadiazine.

TEST YOURSELF

1. What are sulpha drugs ? Give the mechanism of their action.
2. Describe the synthesis and uses of the following sulpha drugs :
   (i) Sulphacetamide (ii) Sulphaguanidine (iii) Sulphapyridine
   (iv) Sulphadiazine (v) Sulphathiazole (vi) Sulphamethazine
3. Antipyretics are medicinal compounds which :
   (i) Relieve pain (ii) Lower body tempertaure
   (iii) Control malaria (iv) Can kill other micro-organisms.
4. Sulpha drugs are the derivatives of :
   (i) Quinine (ii) Pencillin (iii) Sulphanilamide
   (iv) Sulphapyridine
5. **Fill in the blanks :**
   (i) The drugs used for reducing pain are called ....
   (ii) Sulpha drugs are .... toxic than antibiotics.
   (iii) The sulpha drug used in pneumonia is ....
   (iv) .... is used for curing dysentry.

ANSWERS

3. (b), **4.** (c), **5.** (i) analgesics (ii) less (iii) sulphapyridine (iv) sulphaguanidine.